EPA/540/AR-93/517
April 1993

Toronto Harbour Commissioners (THC) Soil Recycle Treatment Train

Applications Analysis Report

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency under Contract No. 68-C0-0048 and the Superfund Innovative Technology Evaluation (SITE) Program. It has been subjected to the Agency's peer review and administrative review, and it has been approved for publication as a U.S. EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

The Superfund Innovative Technology Evaluation (SITE) Program was authorized in the 1986 Superfund Amendments. The Program is a joint effort between EPA's Office of Research and Development & Office of Solid Waste and Emergency Response. The purpose of the program is to assist the development of hazardous waste treatment technologies necessary to implement new cleanup standards which require greater reliance on permanent remedies. This is accomplished through technology demonstrations designed to provide engineering and cost data on selected technologies.

This project consists of a demonstration of the Toronto Harbour Commissioners (THC) Soil Recycle Treatment Train. The Treatment Train consists of three processes. The first process utilizes an attrition soil wash process to separate relatively uncontaminated soil from a more heavily contaminated fine slurry. The contaminated fine slurry is then further processed in a metals removal process or a bioslurry reactor process or both to remove organic contaminants and heavy metals contamination. The Toronto Harbour Commissioners conducted a long-term evaluation of this treatment train at a 55 tons per day pilot plant at 185 Cherry Street in the port of Toronto, located in Toronto, Ontario, Canada. The SITE project examined in detail the processing of soil from one of the sites being evaluated in the overall project. THC has estimated that as much as 2,200,000 tons of soil from locations within the Toronto Port Industrial District may require some form of treatment due to heavy metals and/or organic contamination. The goals of this study were to evaluate the technical effectiveness and economics of a treatment process sequence and to assess the potential applicability of the process to other wastes and/or other Superfund and hazardous waste sites.

Additional copies of this report may be obtained at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati Ohio, 45268, using the EPA document number found on the report's front cover. Once this supply is exhausted, copies can be purchased from the National Technical Information Service, Ravensworth Bldg., Springfield, VA, 22161, 703-487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency

Abstract

The Toronto Harbour Commissioners (THC) have developed a soil treatment train designed to treat inorganic and organic contaminants in soils. THC has conducted a large-scale demonstration of these technologies in an attempt to establish that contaminated soils at the Toronto Port Industrial District can be treated to attain contaminant levels below the THC Criteria Levels for Industrial Soils without utilizing incineration processes.

The THC's treatment train evaluated during this SITE Demonstration consists of three soil remediation technologies: an attrition soil washing technology, inorganic removal by chelation, and a chemical and biological treatment to reduce organic contaminants. The overall process sequence is determined by the specific contaminants in the soil to be treated.

Sampling, data collection and analysis as part of the THC demonstration were conducted under the SITE program utilizing appropriate analytical procedures as specified in SW846 to provide a consistent basis for comparing these technologies to other technologies evaluated under the SITE program.

Based on the results of the SITE demonstration project at the THC Soil Recycling Demonstration Project, Toronto, Ontario, Canada and information concerning the overall THC project, several conclusions can be drawn.

- The primary developer's claim that the gravel, sand, and fine soil products will meet the THC criteria for reuse as fill material at industrial/ commercial sites was achieved by the gravel and sand products, representing 79.6 percent of products. The fine soil representing 18.8 percent of the products exhibits significant reduction in PAH compounds as a result of biological processing but did not meet the criteria level of 2.4 mg/kg for benzo(a)pyrene.

- The attrition soil wash plant produced a gravel (<1.97 in; >0.24 in) and a sand (<0.24 in; >0.0025 in) that achieved the primary THC criteria. It should be noted that the only parameter which exceeded this THC criteria in the feed was naphthalene. The process exhibited removal rates for organic contaminants of 67 percent or greater for the gravel product which accounted for 11.5 percent of the product output. The sand product exhibited organic removal rates of 78 percent or greater while accounting for 68.1 percent of the product output. The process concentrated the organic contaminants into a contaminated fine slurry (<0.0025 in) which accounted for 18.8 percent of the process output while accounting for 74 percent or more of the organic contaminants.

- The metals contamination levels actually encountered during pilot-scale processing of the test soil were so low that there was no need to use the metals removal process. Limited data were developed for the efficiency of the metals removal process by sampling a run of a metals-rich slurry from another soil. The reactor achieved the following removal efficiencies: copper-96 percent, lead-71 percent, nickel-71 percent and zinc-64 percent. Higher removal efficiencies are claimed by the developer when processing more highly contaminated soils.

- The bioslurry process exhibited limited reduction in oil and grease. A similar comparison for other parameters yielded the following: TRPH reduction of 60 percent, naphthalene at least 97 percent, and benzo(a)pyrene approximately 70 percent.

Contents

Contents (Cont'd)

Contents (Cont'd)

Page

Contents (Cont'd)

Tables

Tables (Cont'd)

Figures

Abbreviations

ARAR	Applicable or Relevant and Appropriate Requirements
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
cfm	Cubic feet per minute
EPA	Environmental Protection Agency
HSWA	Hazardous and Solid Waste Amendments to RCRA - 1984
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
PAH	Polynuclear Aromatic Hydrocarbon
PID	Port Industrial District
POTW	Publicly-Owned Treatment Works
mg/kg	Milligrams per kilogram
MOE	Ontario Ministry of the Environment
NPDES	National Pollutant Discharge Elimination System
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendments and Reauthorization Act
SITE	Superfund Innovative Technology Evaluation
TCLP	Toxicity Characteristic Leaching Procedure
THC	Toronto Harbour Commissioners
TRPH	Total Recoverable Petroleum Hydrocarbons

Conversion Factors

	English (US)	x	Factor	=	Metric
Area:	1 ft^2	x	9.2903×10^{-2}	=	m^2
	1 in2	x	6.4516	=	cm^2
Flow Rate:	1 gal/min	x	6.3090×10^{-5}	=	m^3/s
	1 gal/min	x	6.3090×10^{-2}	=	L/s
	1 Mgal/d	x	43.8126	=	L/s
	1 Mgal/d	x	3.7854×10^{3}	=	m^3/d
	1 Mgal/d	x	4.3813×10^{-2}	=	m^3/s
Length:	1 ft	x	0.3048	=	m
	1 in	x	2.54	=	cm
	1 yd	x	0.9144	=	m
Mass:	1 lb	x	4.5359×10^{2}	=	g
	1 lb	x	0.4536	=	kg
	1 ton	x	0.9072	=	Kkg
Volume:	1 ft^3	x	28.3168	=	L
	1 ft^3	x	2.8317×10^{-2}	=	m^3
	1 gal	x	3.7854	=	L
	1 gal	x	3.7854×10^{-3}	=	m^3

ft = foot, ft^2 = square foot, ft^3 = cubic feet
in = inch, in^2 = square inch
yd = yard
lb = pound
gal = gallon
gal/min (or gpm) = gallons per minute
Mgal/d (or MGD) = million gallons per day
m = meter, m^2 = square meter, m^3 = cubic meter
cm = centimeter, cm^2 = square centimeter
L = liter
g = gram
kg = kilogram
m^3/s = cubic meters per second
L/s = liters per second
m^3/d = cubic meters per day

Acknowledgment

This report was directed and coordinated by Ms. Teri Richardson, EPA SITE Project Manager in the Risk Reduction Engineering Laboratory - Cincinnati, Ohio.

This report was prepared for EPA's Superfund Innovative Technology Evaluation (SITE) Program by Mr. Leo C. Ehrenreich, Mr. Andrew Matuson, Mr. Joseph Peters, Mr. Joseph Evans and supporting staff at Science Applications International Corporation (SAIC) for the U.S. Environmental Protection Agency under Contract No. 68-CO-0048. The Work Assignment Manager for this project was Mr. Leo Ehrenreich.

The cooperation and participation of Mr. Dennis Lang of the Toronto Harbour Commissioner staff, Dr. Diana Murato of Zenon Environmental Inc., Ms. Natalie Dame, Ms. Lucille Hicks and Mr. Al Rouse of SNC-Lavalin, Dr. Irving DeVoe of DeVoe Environmental Laboratory throughout the course of the project and in review of this report are gratefully acknowledged.

Finally, the project could not have been carried out without the efforts of the many SAIC, S-Cubed, and Aerovironment personnel who were responsible for the actual sample collection and analyses.

Section 1

Executive Summary

1.1 Introduction

The Toronto Harbour Commissioners (THC) have developed a soil treatment train designed to treat inorganic and organic contaminants in soils. THC has conducted a large-scale demonstration of these technologies in an attempt to establish that contaminated soils at the Toronto Port Industrial District can be treated to attain contaminant levels below the Ontario Ministry of the Environment (MOE) Criteria Levels for Industrial Soils without utilizing incineration processes. Table 1 presents the MOE Criteria plus additional target criteria set by the developer, the THC. Collectively, these criteria are referred to as the "THC criteria".

The THC's treatment train evaluated during the SITE demonstration consists of three soil remediation technologies: an attrition soil washer to segregate the soil into uncontaminated coarse material and highly contaminated fines, a metals removal process by chelation, and chemical and biological treatment for reduction of organic contaminants. The overall process sequence is determined by the specific contaminants in the soil to be treated.

Sampling, data collection, and analysis were conducted under the SITE program to provide a consistent basis for comparing these technologies to other technologies.

1.2 Conclusions

Based on the results of the SITE demonstration project at the THC Soil Recycling Demonstration Plant, Toronto, Ontario, Canada and information concerning the overall THC project several conclusions can be drawn:

Table 1. THC Target Criteria for Selected Parameter for Soils for Commercial/Industrial Land Use and Results of Demonstration

Parameter	THC Target Course Textured Soil[1]	THC Target Medium & Fine Textured Soil	Feed[4] Soil	Gravel[4]	Sand[4]	Fine[5] Soil
Conventional						
Oil and Grease (%)	1	1	0.82	0.33	0.22	2.5
TRPH (mg/kg)	-	-	2500	800	620	5400
Total Metals (mg/kg)						
Copper	225	300	18.3	6.4	13.8	84
Lead	750	1000	115.0	45.3	46.0	548
Zinc	600	800	82.5	46.0	34.0	343
Organic Compounds (mg/kg)						
Naphthalene	8.0[3]	8.0[3]	11.2	2.5	2.1	1.3[(6)]
Benzo(a)pyrene	2.4[2]	2.4[2]	1.9	0.6	0.5	(2.6)[(7)]

1. Defined as greater than 70% sand and less than 17% organic matter.
2. Clean-up levels are shown for organic compounds. If soils exceed these levels, then the soil is considered hazardous and remediation is required.
3. If these trigger levels are exceeded, the MOE will make a determination on a case by case basis regarding the need for remediation.
4. Average of six composite samples.
5. Average of six sample's from bioslurry reactor batch 2.
6. Values reported is estimated detection limit for this parameter.
7. Values shown is below quantitation limit for procedures. Values shown is estimated.

1.2.1 THC Treatment Train

- The primary developer's claim for the production of gravel and sand that meet the THC Target criteria for medium to fine soil suitable for industrial/commercial sites was achieved for the sand and gravel products. The fine soil from the biological treatment process exhibited anomalous oil and grease behavior and, although exhibiting significant reduction in PAH compounds, did not meet the target level of 2.4 ppm for benzo(a)pyrene.

- An assessment of the developer's claims relative to metals treatment was not possible since soil excavated for this study did not exhibit the metal contamination levels expected based on earlier field sampling. Limited data was obtained for this process by sampling another soil with moderate metals contamination.

- The hydrocyclone device used for final dewatering of the fine soil did not produce a dry product. As a result, the final product from the process was a slurry. The use of this technology was an attempt to find a less expensive alternative to filter press technology, and was not a significant component in the total treatment train demonstration.

1.2.2 Soil Wash Process

- The attrition soil wash plant produced a gravel (<1.97 in; >0.24 in) and a sand (<0.24 in; >0.0025 in) that met the THC Target criteria. The only parameter which exceeded the THC criteria in the feed soil was naphthalene. The process exhibited removal rates for organic contaminants (oil & grease, total recoverable petroleum hydrocarbons (TRPH), naphthalene, benzo (a) pyrene) of 67 percent or greater for the gravel product. This product accounted for 11.5 percent of total process mass output while accounting for 4 percent or less of the organic contaminants in the product streams.

- Removal rates for organic contaminants (oil & grease, TRPH, naphthalene, benzo(a)pyrene) were 78 percent or greater for the sand. This product accounted for about 68.1 percent of the process output while accounting for 15 percent or less of the organic contaminants in the product stream.

- The process concentrated the organic contaminants into a contaminated fine slurry (<0.0025 in) which accounted for about 18.8 percent of the process output mass while accounting for 74 percent or more of the organic contaminants.

- The process also produced a contaminated coal/peat product (<0.24 in; >0.00025 in) which represented about 1.6 percent of the process output while accounting for 6 percent or more of the organic contaminants. This waste stream will require disposal (most likely by incineration).

- The feed soil exhibited low heavy metals contaminant levels (copper 18 ppm, lead 115 ppm and zinc: 83 ppm). The wash process concentrated these contaminants in the fine slurry (18.8 percent of the process mass output) accounting for 59 percent or more of these metals in the process output streams.

1.2.3 Bioslurry Process

- The clean fine soil product resulting from the bioslurry process did not meet the primary objective when assessed using the appropriate analytical procedures from SW-846 as universally applied in SITE evaluations. The developer has investigated other analytical procedures they believe may be appropriate for slurries with high biomass content that may yield different results. The problem parameters were oil & grease and benzo(a)pyrene. The benzo(a)pyrene concentration, although reduced by the process, did not meet the THC Target Criteria level of 2.4 ppm.

- The bioslurry process provided limited reduction in oil and grease when comparing inlet to output samples. A similar comparison for other parameters yields the following reductions: Total Recoverable Petroleum Hydrocarbons (TRPH) 60 percent; naphthalene at least 97 percent; and benzo(a)pyrene approximately 70 percent.

- Emission sampling of the ventilation system serving the biological treatment system did not detect PAH compounds, but detection limits were very high due to a high concentration of light hydrocarbons in the exhaust stream. These light hydrocarbons were tentatively identified as a petroleum distillate in the range of diesel oil to Stoddard solvent (C_9 - C_{16} paraffins). Total gaseous, non-methane organic compounds were detected at levels which indicate 220 lbs per day of emissions. (The data illustrate that significant air stripping is occurring in the bioreactor, and this must be accounted for in the design.) The bioslurry process was developed to collect and treat volatilized hydrocarbons in two biofilters. These active filtration units were followed by an activated carbon bed to polish the air and remove any residual contaminant. Stack testing by the developer indicates hydrocarbon emissions are below detection levels.

1.2.4 Metals Removal Process

- The metals contamination levels actually encountered eliminated the need for utilizing the metals removal process for this soil. Limited data were developed for the efficiency of the metals removal process by sampling a process run of a metal-rich slurry from another soil. The reactor achieved the following removal efficiencies based on metals concentrations in the inlet versus the outlet samples: copper-96 percent, lead-71 percent, nickel-71 percent and zinc-64 percent.

- The metals removal process became fouled with oil and grease forcing the operation to shut down prematurely. This may be a limitation on the process in that slurries with free oil and grease cannot be processed directly. This problem may be overcome by treating the organic contaminant first and then utilizing the metals removal process.

1.2.5 Process Costs

- The costs of the treatment system were examined on both an integrated and on a unit process basis. This will allow the decision maker to estimate costs for other soil applications based on the processes that would be required for treating the specific soil. The cost information was developed by THC based on analysis of the overall THC demonstration. The overall cost of operation of a 6.6 tons per hour soil wash, metals removal and bioslurry treatment train is estimated at $219 per ton. The individual process costs that make up this estimate are:

Soil Washing:	$80/ton of feed soil.
Metals Removal:	$96/ton of feed soil.
Bioslurry Process:	$43/ton of feed soil.

- The developer estimates that treatment costs using a 50-60 tons per hour fixed facility operating continuously at full capacity would be about $116 per ton of raw feed assuming the fines require metals removal and organics reduction.

1.3 Summary of Suitability of THC Treatment Train for CERCLA Corrective Actions

1.3.1 Overall Protection of Human Health and the Environment

The technology provides a means of removing organic and metallic contaminants from the soil which should leave the remaining soil relatively uncontaminated and suitable for a broader range of uses.

1.3.2 Compliance with ARARs

Data developed during this study suggests the soil washing can reduce organic contaminants by 65 percent or more of the levels in the feed soil, and also reduce metals contaminant levels by 50 percent or more in the products that represent 70 to 80 percent of the feed. Fines can be further treated using the metals removal process which can achieve removals of 60 to 90 percent of the metals present in the fines. Higher metals removal can be achieved using a multiple pass configuration but with an attendant increase in cost. The bioslurry reactor process exhibits removal in the 70 percent range for PAH contaminants. Where contaminant removal of these magnitudes would be useful at a specific site, a treatability experiment to establish likely removal rates may be warranted.

1.3.3 Long Term Effectiveness and Permanence

The processes remove significant portions of the contaminants from the soil with the fines. If the residual levels in the treated soil do not pose a health or environmental risk, this represents a permanent remediation.

1.3.4 Reduction of Toxicity, Mobility, and Volume Through Treatment

- While some reductions in toxicity are accomplished as a function of the removal rates, highly hazardous constituents may require more complete removal.

- The process does not appear to provide any additional immobilization of the remaining contaminants.

- Two products, other than treated soil, which represent a small fraction of the feed soil are produced. A coal/peat waste stream which amounts to 1.6 percent of the feed will require disposal, most likely by incineration. The heavy metals will represent a very small fraction of the feed and are recovered in metallic form by electrowinning. This product may represent a recycling opportunity.

1.3.5 Short-Term Effectiveness

- The protection of the community during remedial actions will center on the excavation and transportation of the soil to the process units. Vapor releases and fugitive dust would be the primary concerns.

- Worker protection would require careful attention to health and safety and workplace monitoring.

- Environmental releases to wastewater and air emissions are expected to be minimal during processing.

1.3.6 Implementability

- Reliability of the soil washing process has been established by a decade of use in Europe. The long term reliability of the metals removal and bioslurry reactor processes have not been established.

- The unit evaluated is capable of processing 50 to 150 tons per day of feed soil. Actual production levels will be a function of the amount of fines in the soil and the removal levels required to achieve acceptable levels of contaminants in the clean soil products.

- The process units evaluated have been designed to be trailer transportable. Assembly will require the use of a crane and experienced personnel. Process operation will require experienced operators.

- The soil washing technology could be utilized with incineration of the contaminated fines for total organics removal. If necessary, the metals removal process could be used after incineration for removal of heavy metals from the incineration residue.

- The effectiveness of the process can be monitored by sampling of the soil product streams.

1.3.7 Cost

- Capital cost of the 6.6 ton per hour trailer transportable process units is estimated at $2,250,000.

- Operating costs are a function of the amount of throughput fines in the soil to be treated, the contaminants present, and the removal rates required to treat the contaminated slurry. In the case of 33 percent fines, single pass metals removal and biological treatment with 10 days detention, the total costs have been estimated at $219 per ton of feed soil. This includes $80 per ton of feed soil for soil washing, $96 per ton of feed soil for metals removal, and $43 per ton of feed soil for biological treatment.

- THC has provided an estimate of the cost of treatment in a fixed facility with a 55 ton/hour continuous soil feed rate of $116 per ton of feed.

1.4 Discussion of Conclusions

The SITE program evaluation and the developer's more extensive demonstration at the Toronto Harbour Commissioners Soil Recycling Demonstration plant at Toronto, Ontario, Canada has utilized a process scheme that concentrates contaminants in a fine slurry stream using a soil wash process and subsequent treatment of the fine slurry with processes that remove a significant portion of the contaminants. Because of the nature of this SITE study and the process scheme itself, the following discussion is presented in terms of the process units evaluated, i.e. Soil Washer, Bioslurry Reactor and Metals Removal Process.

An extensive Quality Assurance (QA) program was conducted by SAIC in conjunction with EPA's QA program, including audits and data review along with corrective action procedures and special studies to resolve specific data quality problems. These programs are the basis for the quality of the data derived from the SITE demonstration. Discussion of the QA program and the results of audits, data reviews, and special studies can be found in the Technology Evaluation Report.

1.4.1 Soil Washing

The conclusions presented earlier in this section are based primarily on the data developed during the SITE demonstration.

The development of true mass balance data was precluded by the size of the pilot facility and its 6.6 ton per hour feed rate and the fact that the SITE demonstration sampling was not the primary objective of the operator. Rough material balance data were developed by using the same volume-based approach the operator used in monitoring production.

The developer's overall mass balance for feed and products for the entire 1040 ton run of this soil compared well with data gathered during the processing of 122 tons of this soil during the SITE sampling event.

When evaluating removal efficiencies, the SITE developed estimates for mass balance were used. The conclusions drawn would not be materially affected if the THC-developed findings were used.

The analysis of samples of the recycled water stream used in the soil wash process indicates that the contaminants of interest do not report to the aqueous phase. Therefore the assessment of removal efficiencies was based on the analysis of the product samples and the mass balance.

1.4.2 Bioslurry Reactor

The soil wash process produces a fine slurry product stream containing about 70 percent of the organic contaminants originally present in the feed soil while accounting for a small fraction of the original soil mass. In the SITE demonstration, the contaminated fine soil accounted for about 19 percent of the feed by weight. The THC project has established an objective of using processes other than incineration, which they recognize would have acceptance problems in the Toronto area. This led the developer to consider a biological treatment system, which has the additional potential advantage of reduced cost.

The developer planned to use a continuous process for this biological treatment system but early experience with the bioslurry reactor process disclosed variable analytical results. As a result, the developer had not moved beyond batch evaluations at the time of the SITE sampling. EPA's plan, which was designed to sample the process during steady-state operation was, therefore, not possible to achieve. An alternative approach was adopted for the SITE sampling, which involved extensive sampling of the discharge from two bioslurry reactor batches. The first batch was accumulated from the first four days of fine slurry production from the soil wash process. A total residence time in the biosystem of 41 days was utilized. The second batch, accumulated primarily during the SITE demonstration, had a total residence time in the system of 30 days. Erratic analytical results made an assessment of optimum residence time very difficult. As a result, the residence times used should not be considered as optimized.

The conclusions listed earlier in this section for the bioslurry reactor process are based primarily on the data developed during the SITE demonstration and reinforced by similar results obtained by the developer.

The developer believes that anomalously high oil and grease analytical results are caused by extraction of the biomass in the analytical procedure. The Total Recoverable Petroleum Hydrocarbon (TRPH) reductions observed during the SITE study provide some support for this hypothesis since the TRPH reduction is considerably greater than the oil and grease reduction. TRPH levels achieved suggest that some hydrocarbon contamination remains after treatment. The developer is continuing the evaluation and development of analytical procedures that may be appropriate for soils with high biomass content. At this point, however, the fine soil product does not meet the THC Target Criteria for oil and grease when this parameter is assessed using SW-846 Method 9071.

The benzo(a)pyrene concentration in the biologically treated fine soil slightly exceeds the THC Target Criteria when assessed utilizing SW-846 techniques. Different results may be obtained with other procedures. It may be possible to further optimize the biological system, perhaps with the addition of other cultures specifically selected for PAH digestion capability.

1.4.3 Metals Removal Process

The actual soil processed during the SITE demonstration was not contaminated with heavy metals. As a result, there was no need to run this soil through the metals removal process. At the time of the SITE evaluation, the metals removal process was just being restarted after a long period of inactivity. The acidified fine slurry from another soil produced by the soil wash process had been sitting in the tank for about one month. Because the sampling team was on site for the SITE demonstration, sampling of this material was used to provide some information concerning the metals removal process. The process also differed from normal operation in that the tank agitator was shut down. It was only possible to sample the inlet and outlet of the tubular reactor. Sampling of the original soil feed and effective sampling of soil particles which settled in the feed tank was not possible. The data developed are, therefore, limited to use in assessing the effectiveness of the tubular reactor/contactor and its solid chelating agent in reducing the metals content of a slurry stream. The SITE demonstration results were consistent with the developer's experience.

1.5 Costs

Cost data were developed for the system as demonstrated at the Toronto Harbour Commissioners Soil Recycling Demonstration Plant by THC. The estimate is based on an analysis of the cost information developed during the approximately nine months of operation of the facility. The costs developed assume the facility is being operated to process soil without conflicting information-gathering objectives.

The THC cost estimates were developed in Canadian dollars. The costs presented in this report have been converted to U.S. dollars by multiplying by an exchange rate factor of 0.8.

The cost estimates for the current pilot facility, as well as the full- scale plant, do not include the cost of disposal of the coal/peat fraction or costs associated with effective dewatering of the final fine product.

The cost estimates for the current pilot facility, as well as the full- scale plant, do not include the cost of disposal of the coal/peat fraction or costs associated with effective dewatering of the final fine product.

Section 2

Introduction

2.1 The SITE Program

The EPA's Office of Solid Waste and Emergency Response (OSWER) and the Office of Research and Development (ORD) established the Superfund Innovative Technology Evaluation (SITE) Program in 1986 to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its seventh year, the SITE Program is helping to provide the treatment technologies necessary to meet new federal and state clean-up standards aimed at permanent remedies, rather than short-term corrections. The SITE Program includes three components: the Demonstration Program, the Emerging Technologies Program and the Measurements and Monitoring Technologies Program.

The major focus has been on the Demonstration Program, which is designed to provide engineering and cost data on selected technologies. EPA and the developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at sites, usually Superfund sites agreed to by EPA and the developer. EPA is responsible for sampling, analyzing, and evaluating all test results. The outcome is an assessment of the technology's performance, reliability, and cost. This information, used in conjunction with other data, enables EPA and state decision-makers to select the most appropriate technologies for the clean-up of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to EPA's annual solicitation. To qualify for the program, a new technology must be at the pilot- or full-scale and offer some advantage over existing comparable technologies. Mobile technologies are of particular interest to EPA.

Once EPA accepts a proposal, EPA and the developer work with the EPA Regional Offices and state agencies to identify a site containing wastes suitable for testing the capabilities of the technology. EPA prepares a detailed sampling and analysis plan designed to evaluate the technology thoroughly and to ensure that the resulting data are reliable. This project had a somewhat different nature. The Toronto Harbour Commissioners (THC) had developed a demonstration project to evaluate an approach for remediation of a large number of industrial/commercial sites located in the Toronto Port Industrial District (PID). This demonstration involved the operation of a Pilot Demonstration Plant for approximately nine months to demonstrate the feasibility of recycling soil with both organic and inorganic contamination as well as developing information for the eventual design of a full-scale facility based on the technologies evaluated. THC, in this case, did not fit the classical developers role in a typical SITE demonstration. When the program was initiated, THC had no business interest in the technologies being evaluated. During the course of the demonstration some changes in the relationship between THC and its contractors took place which resulted in THC taking a partnership interest in the metals removal process technology.

EPA was offered the opportunity to participate in this project. After meeting with the THC and discussing their plan, an approach was developed by EPA. Normally a demonstration may require a few days to several months, depending on the type of process and the quantity of waste needed to assess the technology. Thus, while it may be possible to obtain meaningful results in a demonstration of one week using an incineration process, where contaminants are destroyed in seconds, this is not the case for a process sequence such as that offered by the Toronto Harbour Commissioners Soil Recycling Demonstration, where operational reliability, integration of outputs from one unit to others, and biological and system acclimation and stability must be examined. In order to evaluate such parameters, THC determined that a minimum of six months of operations was necessary to evaluate the complete process train while processing three different soils from the PID. EPA elected to sample the process during the processing of Soil B, which based on field sampling was expected to exhibit relatively high organic (oil and grease, PAH compounds) and inorganic (heavy metals) contaminants. The sampling undertaken by EPA was of relatively short duration but it was expected that when the results were combined with THC data, a sound basis for analysis of the technology would be obtained. Ultimately, the Demonstration Program leads to an analysis of the technology's overall applicability to Superfund problems.

The second principal element of the SITE Program is the Emerging Technologies Program, which fosters the further investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies could lead to the development of systems ready for field demonstration. A third component of the SITE Program, the Measurement and Monitoring Technologies Program, provides assistance in the development and demonstration of innovative technologies to better characterize Superfund sites.

2.2 *SITE Program Reports*

The results of the SITE Demonstration Program are reported in two documents, the Technology Evaluation Report and the Applications Analysis Report. The Technology Evaluation Report provides a comprehensive description of the demonstration and its results for engineers responsible for detailed evaluation of the technology relative to other specific sites and waste situations. These technical evaluators will want to understand thoroughly the performance of the technology during the demonstration, and the advantages, risks, and costs of the technology for the given application.

The Applications Analysis Report is directed to officials responsible for selecting and implementing remedial actions for specific sites. This report provides sufficient information for a preliminary determination of whether the technology merits detailed consideration as an option in cleaning up a specific site. If the candidate technology described in the Applications Analysis appears to meet the needs of the site engineers, a more thorough assessment can be made based on the Technology Evaluation Report and information from remedial investigations for the specific site. In summary, the Applications Analysis will assist in determining whether the specific technology should be considered further as an option for a particular clean-up situation.

Each SITE demonstration evaluates the performance of a technology while treating the particular waste matrix found at the demonstration site. Additional data from other projects carried out by the developer also are presented where available.

Usually, the waste and/or soil at other sites requiring remediation will differ in some way from the waste matrix tested. Waste characteristic differences could affect waste treatability and use of the demonstration technology at other sites. Successful demonstration of a technology at one site does not ensure that the same technology or configuration will work equally well at other locations. The operating range over which the technology performs satisfactorily can only be determined by examining a broad range of wastes and sites. This report provides an indication of the applicability of the Attrition Soil Washer, the Bioslurry-Reactor, and the Metals Removal Process, both as individual operating units and as an integrated system, by presenting and examining the SITE demonstration test data and data from the developer that are available from other applications of the technology.

To enable and encourage the general use of demonstrated technologies, EPA considers the probable applicability of each technology to sites and wastes in addition to those tested, and strives to estimate the technology's likely costs in these applications. The results of these analyses are made available through the Applications Analysis Report.

2.3 *Key Contacts*

For more information on the demonstration of the THC Soil Recycle System for contaminated soil please contact:

1. Technology Developer concerning the process:

   Mr. Dennis Lang
   The Toronto Harbour Commissions
   60 Harbour Street
   Toronto, Ontario, Canada M5J 1B7
   (416) 863-2047
   FAX: (416) 863-4830

2. EPA Project Manager concerning the SITE Demonstration:

   Ms. Teri Richardson
   Risk Reduction Engineering Laboratory
   26 West Martin Luther King Drive
   Cincinnati, Ohio 45268
   (513) 569-7949

Section 3

Technology Applications Analysis

3.1 *Introduction*

This section addresses the potential applicability of the Toronto Harbour Commissioners Soil Recycle System to other soils and Superfund site situations where petroleum hydrocarbons, polynuclear aromatic hydrocarbons and heavy metals are the pollutants of primary interest. The demonstration at the Toronto Harbour Commissioners' Soil Recycle Demonstration Plant provides a data base for use in assessing the effectiveness and applicability of the technology to other cleanups. This data base is complemented by information from further studies of the same soil, as well as other soils and wastes conducted by THC during the first nine months of 1992.

3.2 *Conclusions*

3.2.1 Overall Process Train

Based on the results of the testing conducted during this evaluation, the primary developer claim, the production of gravel, sand and fine soil that meet the THC Target criteria (see Table 1) for medium to fine soil suitable for industrial/commercial sites, was not achieved. The problem appears to center on the biological treatment process, which exhibited variable behavior with regard to the oil and grease parameter. Although exhibiting significant reduction in PAH compounds, the process did not meet the target level of 2.4 ppm for benzo(a)pyrene. An assessment of the developer's claims relative to metals treatment was not possible since the 1040 tons of soil excavated for this study did not exhibit the metals contamination levels expected based on the field sampling.

The developer employed a hydrocyclone device for final dewatering of the clean fine soil. This technology was not successful and as a result the final product from the process was a slurry. Fine product dewatering will require further evaluation by the developer or will require another technology.

3.2.2 Individual Processes

3.2.2.1 Soil Washing

The attrition soil wash plant produced a gravel and a sand product that met the primary THC Target criteria. It should be noted that the only parameter that exceeded the THC criterion in the feed was naphthalene. Nevertheless, the process exhibited removal rates for organic contaminants (oil & grease, TRPH, naphthalene, benzo(a)pyrene) of 67 percent or greater for the gravel product. This product accounted for 11.5 percent of total process mass output (dry weight basis) and 4 percent or less of the organic contaminants in the product streams.

This process exhibited removal rates for organic contaminants (oil & grease, TRPH, naphthalene, benzo(a) pyrene) of 78 percent or greater for the sand product. This product accounted for 68.1 percent of the process mass output while accounting for 15 percent or less of the organic contaminants in the product stream.

The process concentrated the organic contaminants into a fine slurry stream that accounted for about 18.8 percent of the process mass output and 74 percent or more of the organic contaminants.

The process also produced a contaminated coal/peat product which represented 1.6 percent of the process output and accounted for 6 percent or more of the organic contaminants. This waste stream will require disposal (most likely by incineration).

The feed soil exhibited low heavy metals contaminant concentrations (copper-17 ppm, lead-115 ppm and zinc-83 ppm). The wash process concentrated these contaminants in the fine slurry which accounted for 18.8 percent of the process output and 59 percent or greater of these metals in the process output streams.

3.2.2.2 Bioslurry Process

The clean fine soil product resulting from the bioslurry process did not meet the primary objective when assessed using the appropriate analytical procedures from SW846 as universally applied in SITE evaluations. The developer has investigated other analytical procedures they believe may be appropriate for soils with high biomass concentrations that may yield different results. The problem parameters were oil & grease and benzo(a)pyrene. The benzo(a)pyrene concentration, although reduced by the process, did not meet the THC Target Criteria level of 2.4 ppm.

The bioslurry process provided limited reduction in oil and grease when comparing inlet to output samples. A similar comparison for other parameters yields the following reduction: Total Recoverable Petroleum Hydrocarbons (TRPH) 52 percent; naphthalene at least 97 percent; and benzo(a) pyrene approximately 70 percent.

3.2.2.3 Metals Removal Process

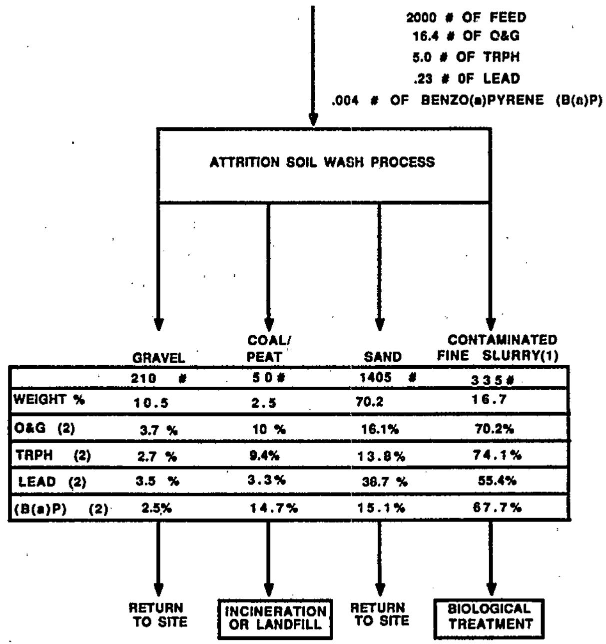
The metals contamination concentrations of the soil that was moved to the pilot facility for processing were low and eliminated the need for utilizing the metals removal process for this soil. Limited data were developed for the efficiency of the solid chelating agent and tubular reactor process by sampling a process run of a metal-rich slurry for another soil which had been processed earlier. The reactor achieved the following removal efficiencies based on metals concentrations in the inlet versus the outlet samples - copper-96 percent, lead-71 percent, nickel-71 percent and zinc-63 percent. No assessment of the process ability to achieve the THC Target Criteria was possible because of the sampling circumstances.

During the sampling, the metals removal process became fouled with oil and grease forcing premature termination of the operation. This represents an operational constraint in that if slurries exhibit free oil and grease and metal contamination the free oil and grease should be reduced prior to application of the metals extraction process. Optimization of the materials management at that specific site may also avoid this constraint.

3.3 Technology Evaluation

This SITE program evaluation demonstrated a process scheme that involves three processes to remediate soils contaminated with organics and/or heavy metals. The objective was to determine whether the processes operating in an integrated manner can meet the THC criteria for return of the soil to the site. The primary process is a soil attrition wash process that segregates a contaminated soil into (a) washed gravel, (b) sand, and (c) fine soil. Each output retains whatever contaminants are absorbed, adsorbed or otherwise integrally mixed with the solids. Because of the increasing surface area per unit weight, the fine soil contains a disproportionate fraction of most contaminants, while the gravel is relatively uncontaminated. Investigations carried out by others have established that such soil wash processes can typically handle feed soils with up to 25-35% fine soil. For the fine soil to be returned as "clean" further treatment would usually be required, such as the biodegradation of organics and/or heavy metals removal also studied in this demonstration. Figure 1 presents a simplified diagram illustrating the partition of feed and contaminants to the product streams.

FIGURE 1
PARTITION OF FEED SOIL TO PRODUCT STREAMS.
THC TREATMENT TRAIN(BASED ON SITE DEMONSTRATION DATA)

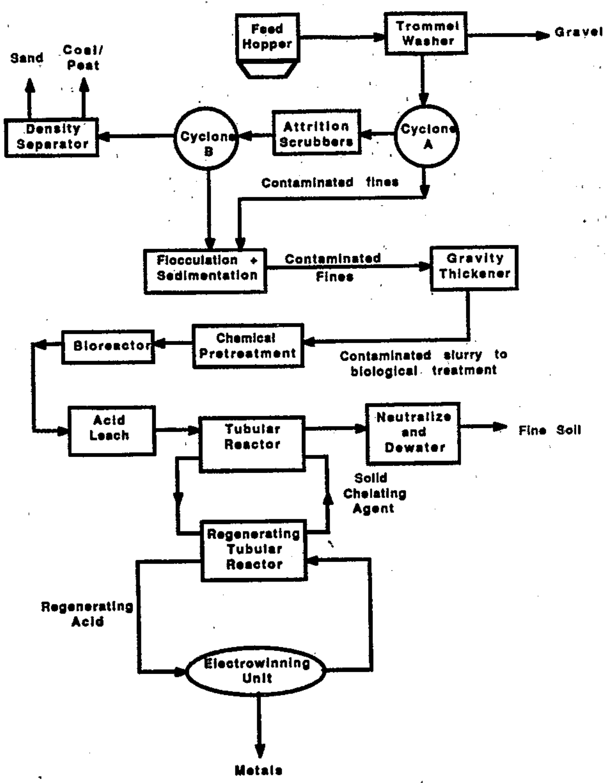


	GRAVEL	COAL/ PEAT	SAND	CONTAMINATED FINE SLURRY(1)
	210 #	50#	1405 #	335#
WEIGHT %	10.5	2.5	70.2	16.7
O&G (2)	3.7 %	10 %	16.1%	70.2%
TRPH (2)	2.7 %	9.4%	13.8%	74.1%
LEAD (2)	3.5 %	3.3%	38.7 %	55.4%
(B(a)P) (2)	2.5%	14.7%	15.1%	67.7%

1.MASS FRACTION OF CONTAMINATED FINES ESTIMATED. BASED ON DIFFERENCE (CONTAMINATED FINES=FEED-(GRAVEL+COAL/PEAT+ SAND)
2.PERCENTAGE OF CONTAMINANT BASED ON TOTAL CONTAMINANTS IN PRODUCT STREAMS

Figure 2 provides a more detailed schematic of the overall treatment train in a configuration that would be used for a soil with significant organic and inorganic heavy metals contamination.

FIGURE 2
SIMPLIFIED PROCESS FLOW DIAGRAM



The results and discussion focus on naphthalene and benzo(a)pyrene because these contaminants exceeded the THC Criteria in the feed or one of the products. Other PAH contaminants were examined but did not exceed the THC criteria in the feed or products. For simplicity, the results are presented only for naphthalene and benzo(a)pyrene.

3.3.1 Soil Washing

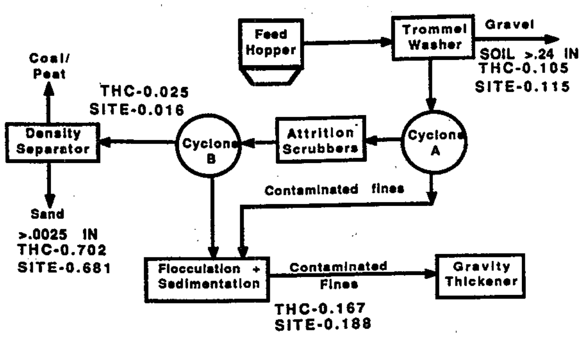
The conclusions presented earlier in this section are based primarily on the data developed during the SITE demonstration. Additional data are presented in Appendix D.

The THC evaluation of the attrition soil wash process for this soil was conducted over a two month period. The feed soil exhibited much higher (by a factor of 3) oil and grease contamination than observed during the site evaluation. THC's results indicated that the gravel product did not meet the THC, oil and grease criterion, however the sand product did meet the criteria during the THC evaluation.

The development of true mass balance data was precluded by the size of the pilot facility and its 6.6 ton per hour feed rate and the fact that the SITE demonstration sampling was not a primary objective of the operation. Rough material balance data were developed by using data the operator used in monitoring production.

A mass balance for the three day SITE demonstration using bucket counts and actual density measurement also was determined. The mass balance results are presented in Figure 3.

FIGURE 3
SIMPLIFIED PROCESS FLOW DIAGRAM FOR SOIL WASH PROCESS
SHOWING PRODUCT FRACTIONS ON A WEIGHT BASIS



When evaluating removal efficiencies the SITE estimates for mass balance were used. However, the conclusions drawn would not be materially affected if the THC developed values were used.

The analysis of samples of the recycled waste stream used in the soil wash process indicated that the contaminants of interest do not report to the aqueous phase. Therefore, the assessment of removal efficiencies was based on the analysis of the product samples and the mass balance.

Determination of compliance with the THC Target Criteria was made by a simple comparison of analytical data to the criteria. The data developed during the SITE demonstration are presented in Table 2. The conclusions previously stated are based on these data and an analysis of Table 3, which presents the weight fraction of each constituent by product stream based on the mass balance. Table 3 also presents the percent of each constituent in terms of the actual fraction found, divided by the fraction expected, assuming that no partitioning by size occurred. The removal efficiency can be determined by subtracting the percentage in parenthesis in Table 3 from 100%.

Table 2. Selected Feed and Product Characteristics of the Attrition Soil Wash Process

	Feed Soil(1)	THC Criteria	<1.97 in. >0.24 in. Gravel(1)	<0.24 in. Coal/Peat Fraction(2)	<0.24 in. >0.0025 in. Sand(1)	<0.0025 in. Contam. Fines(1)
Percent of Output Based on Site Demo. Data		---	11.5	1.6	68.1	18.8
Percent of Output Based on THC Overall Analysis	---	---	10.5	2.5	70.2	16.7
Oil & Grease (mg/kg)	8,200 (6,708-9,700)[3]	10,000	3,300 (1,200-10,400)	38,000 (17,600-51,600)	2,200 (1,400-3,900)	40,000 (26,900-50,500)
TRPH (mg/kg)	2,500 (2,270-3,430)	---	800 (270-1,370)	11,900 (4,760-16,280)	620 (380-960)	14,000 (8,500-19,800)
Copper (mg/kg)	18.3 (9.2-42.2)	225	6.4 (0.7-12.1)	32.9 (22.8-41.7)	13.8 (32-32.4)	83.1 (48.2-135)
Lead (mg/kg)	115 (63.3-127)	750	45.3 (3.2-117)	406 (12.9-749	46 (23.6-82.9)	522 (421-680)
Zinc (mg/kg)	82.5 (40.4-181)	600	46 (2.3-98.6)	210 (46.8-406)	34.1 (15.9-71.4)	344 (192-593)
Naphthalene (mg/kg)	11.2 (5.3-18)	8	2.5 (0.9-2.9)	64 (34-110)	2.1 (1.5-3.1)	51.7 (17-82)
Benzo (a) Pyrene (mg/kg)	1.9 (0.9-2.9)	2.4	0.6 (0.2-1.0)	14.5 (9.6-23)	0.5 (0.2-1.2)	10.0 (9.0-12.0)

(1) Average of six composite samples.
(2) Average of three composite samples.
(3) Range of results.

Table 3. Characteristics of Soil Wash Product Streams (based on SITE mass balance and Site Demonstration Analytical Results)

	<1.97 in. >0.24 in. Gravel	<0.24 in. Coal/Peat Fraction	<0.24 in. >0.0025 in. Sand	<0.0025 in. Contaminated Fines
Fraction of Output	0.115	0.016	0.681	0.188
Oil & Grease	0.038(1) (33)(2)	0.061 (381)	0.149 (22)	0.752 (400)
TRPH	0.028 (24)	0.057 (356)	0.127 (19)	0.788 (419)
Copper	0.028 (24)	0.020 (125)	0.358 (53)	0.594 (316)
Lead	0.037 (32)	0.046 (289)	0.223 (33)	0.694 (369)
Zinc	0.053 (50)	0.057 (230)	0.262 (38)	0.628 (334)
Naphthalene	0.024 (21)	0.082 (513)	0.113 (17)	0.781 (415)
Benzo(a)pyrene	0.028 (24)	0.091 (569)	0.142 (21)	0.740 (394)

(1) Weight fraction of the specific parameter found in the product stream as a fraction of the total weight in all product streams.
(2) Percent of expected value based on feed concentration of respective contaminants and weight fraction of product stream.

3.3.2 Bioslurry Reactor Effectiveness

The soil wash process produces a contaminated fine soil slurry. This product stream contains much of the organic contaminants originally present in the feed soil while accounting for a small fraction of the original soil. In the SITE demonstration, the contaminated fine soil accounted for about 19 percent of the feed by weight. The THC project has established an objective of using processes other than incineration, which they recognize would have acceptance problems in the Toronto area. This led the developer to the use of a biological treatment system which has the additional potential advantage of reduced cost, particularly when compared to incineration.

The developer's early experience with the bioslurry reactor process disclosed variable results. As a result, the developer had not moved beyond batch evaluations at the time of the SITE sampling. The SITE project plan, that was designed to sample a continuous process when it approached steady-state operation, was, therefore, not possible. An alternative approach was adopted that involved extensively sampling the discharge from two bioslurry reactor batches. The first batch accumulated from the first four days of fine slurry had a total process time in the biosystem of 41 days; the second batch had a total process time in the system of 30 days. The information available for evaluation is therefore somewhat restricted. The inlet and outlet results for selected parameters are presented in Table 4.
Erratic analytical results with process samples taken by THC made an assessment of the residence time required to achieve satisfactory results very difficult. As a result, the residence time utilized should not be considered as optimum.

The conclusions listed earlier in this section for the bioslurry reactor process are based primarily on these data and are confirmed by similar results obtained by the developer.

The developer believes that anomalously high oil and grease analytical results are caused by the extraction of biomass in the analytical procedure with a resultant high oil and grease analytical result. The Total Recoverable Petroleum Hydrocarbon (TRPH) reductions observed provide some support for this hypothesis since this parameter exhibits much higher reductions then does oil and grease. The TRPH levels still present do suggest that considerable hydrocarbon contamination remains after the treatment. The fine soil product does not meet the THC Target Criterion of oil and grease when this parameter is assessed using SW-846 Method 9071.

The benzo(a)pyrene concentration in the treated fine soil just exceeds the THC Target Criterion. It may be possible to further optimize the biological system, perhaps with the addition of other cultures specifically selected for PAH digestion capabilities.

3.3.3 Metals Removal Process

The actual soil processed during the SITE demonstration was not contaminated with concentrations of heavy metals that exceeded the THC criteria. Consequently, there was no need to operate the metals removal process. At the time of the SITE demonstration sampling, the metals removal process was just being restarted after a long shut-down period. The metals removal feed tanks contained material from the end of a soil wash run on a different soil concluded about one month earlier. Because the sampling team was on site for

Table 4. Selected Feed and Product Characteristics of the Bioslurry Reactor Process.

	MOE Criteria	Contaminated Fine Slurry(1)	Bioslurry Reactor Batch 1(2)	Bioslurry Reactor Batch 2(2)	Removal Efficiency %(3)
Oil & Grease	1.0%	4.00% (2.7-5.4)(4)	4.98% (3.96-6.08)	2.53% (3.98-2.17)	6
TRPH	---	1.4% (.85-1.98)	.78% (.68-.95)	.54% (.39-.76)	52
Naphthalene	8 mg/kg	51.7 mg/kg (17-82)	<14(5) mg/kg	<13(5) mg/kg <16-<11	97(6)
Benzo(a)pyrene	2.4 mg/kg	10 mg/kg (8.4-12)	3.1 mg/kg (2.0-5.1)	2.6 mg/kg (2.3-3.4)	71

(1) Average of 6 composite samples.
(2) Average of 6 samples taken at 20 minute intervals during discharge of batch.
(3) Removal efficiency based on average value for both batches.
(4) Range of results.
(5) Value reported is average of quantitation limit reported. Detection limit is at least a factor 10 less than the quantitation limit.
(6) Removal efficiency calculated from detection limit estimated by dividing quantitation limit by 10.

the SITE demonstration, a decision was made to sample the inlet and outlet of the tubular reactor even though samples of the soil fed to the system could not be obtained. In addition, no method to effectively sample any soil particles which settled in the feed tank was available. The process also differed from normal operation in that the tank agitator was shut down prior to starting to pump the slurry to the tubular contactor. The data developed is, therefore, limited to providing information on which to assess the effectiveness of the tubular reactor contactor and its solid chelating agent in reducing the metals content of a slurry stream. Our results were consistent with the developers experience. Selected heavy metal data for removal of metals from the liquid stream by the THC metals removal process is presented in Table 5.

Table 5. Selected Heavy Metals Data for Removal of Metals from the Liquid Stream by the THC Metals Removal Process.

Metal	Influent mg/kg	Effluent mg/kg	Removal %
Copper	51.1 (49.2-53.2)[1]	1.8 (0.9-3.0)	96
Lead	100.5 (94.2-112)	29.0 (13.5-46)	71
Nickel	11.7 (10.7-12.7)	3.3 (0.9-7.3)	71
Zinc	277 (264-294)	101 (53-183)	63

1 Range of values.

The developer has information on this process as applied to several soils. In general, the particular solid chelating agent used removes copper most effectively, while lead and nickel are removed at a somewhat lower effectiveness, followed by zinc with a removal rate of about 60 percent.

3.4 Applicable Wastes

It should be emphasized that treatability tests should be undertaken with any candidate soil. In the case of this technology train, an evaluation of each process being considered to treat a specific candidate soil would be required.

There are some general applicability guides that may be useful in assessing if treatability testing should be considered.

The overall treatment approach requires that the contamination of interest can be concentrated in a fine soil fraction which then can be economically processed. This requires that the fine soil fraction not represent too great a percentage of the overall soil. The developer estimates that soil fines should not normally exceed 30 to 35 percent by weight of the overall soil feed. The lower the fine soil concentration in the specific soil, the more favorable the potential economics of the process should be.

The soil wash process is generally tolerant of normal swings in soil particle size. Potential problems arise if metal wire or fibrous vegetation (roots) in the feed soil are common. This leads to operational problems, particularly for the cleanup of the gravels and fine sand fraction and can affect production costs adversely. Another problem could be encountered if the soil exhibits wide swings in the coarse material content. If the maximum concentration of coarse material is known at the design phase, it can be accounted for, but if the design capacity of the trommel washer is exceeded, this could limit the production rate.

The soil wash process is not suited to reduce inorganic target compounds in a soil in which the target compounds are present as a result of the minerals widely dispersed in the soil particles. In this case, little partition by particle size can be expected.

The process configuration utilized depends on the target contaminants being essentially non-soluble in water. If soluble components are present, the ability to reuse water may be affected and some treatment for the aqueous phase may be necessary.

The metals treatment process is not tolerant of free oil and grease. In order to be useful for a soil with free oil and grease, prior treatment will be required.

The metals treatment process may be tailored to specific metals by the selection of ion exchange chelating media. In general, the process depends on being able to dissolve the metals of interest at acidity levels compatabile with the chelating resin system.

The metals treatment process uses an acid solubilization step to make the metals available for removal. The developer has indicated that if the soil matrix contains considerable free calcium carbonate or other carbonates foaming problems may arise when the soil is acidified. In addition, the soluble components may cause handling or dewatering problems when the process effluent is neutralized.

3.5 Site Characteristics

The size and nature of a site that requires remediation may have a considerable effect on the decision to utilize this treatment approach. The volume of material that must be remediated should be in the tens of thousands of tons in order to warrant the use of these technologies. The technology should produce a large volume of clean product soil that can be returned to the excavation site. The type and amount of debris on the site may also be a consideration. Material larger than 2 inches must be removed before the soil can be fed to the wash process. Metal fragments must also be removed as part of a pretreatment operation. If the amount of material or the operational difficulty in removing the debris is excessive, the site may not be suitable for this technology.

This SITE demonstration did not investigate the impact of soil characteristics and particle size distribution on the properties of the output stream. These factors can be expected to have an effect on the masses of the various output streams and may affect throughput rates and the partition of the contaminants to the various product streams. The need for treatability evaluation is therefore further emphasized.

The THC demonstration plant was located on a prepared site in close proximity to the location of the soil sites to be evaluated. The soil wash plant and the metals removal process were designed in trailer transportable modules that can be transported and reassembled for use at a specific site. The bioslurry reactors require relatively large tanks (20,000 gallons), which were designed to be the largest tanks that could still be transported by trailer. The facility at Toronto was located on a paved pad and fully enclosed in a temporary building to allow operation during the relatively harsh Ontario winter season. The facility requires power and a water source. A source of fuel, to maintain water temperature above 55° F, such as natural gas, propane, or fuel oil would provide a cost saving when compared to water heating with electric power. The site is designed to collect all storm runoff and to store it for use in the process. The specific water balance at a site would depend on rainfall and amount of water that leaves the process with product streams. If water must be discharged, a site-specific determination will be required to determine if treatment is necessary prior to discharge to a POTW or to surface waters. In general, a provision should be available to allow discharge if required. The recycled water at the THC site did not show partition of the pollutants to the aqueous phase, but this will be a factor controlled by the nature of the contaminants present.

The use of contaminated water in the process may provide a net benefit at specific sites. For example, if groundwater at a site is contaminated, the metals removal process may also treat this water.

Climate may play a role in determining the type of structure in which the process train would be housed. The soil wash and metals removal process will require at least a covered structure. The bioslurry reactors are closed tanks, and, therefore, could be located on an open pad. If the climate at a site would be expected to exhibit severe winter temperatures, the overall process should be located in an enclosure or heating of tanks and the transfer line may be required. Adverse winter conditions could also cause problems due to the soil freezing, which could effect soil excavation and external materials transfer operations at the facility.

Generally, the process will consume water due to the moisture leaving with the product streams. In climates where seasonable imbalances in precipitation are common, a provision to obtain water for use during dry periods may be appropriate.

3.6 Environmental Regulation Requirements

The THC program is aimed at providing an approach for soil remediation at industrial and commercial sites. The primary regulatory agency responsible is the Province of Ontario Ministry of the Environment. The specific permit issues for the Toronto facility have been addressed by THC.

In the United States, under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and the Superfund Amendments and Reauthorization Act of 1986 (SARA), EPA is responsible for determining the methods and criteria for the removal of waste and residual contamination from a site. The utility and cost effectiveness of the THC Treatment System would be dependent on the extent of decontamination necessary for site restoration and the combination of treatment units appropriate to achieve the required clean-up levels for a particular site. If a waste exhibits a characteristic hazard (e.g., TCLP leachate toxicity) or is a listed hazardous waste, treatment will be required. Specific treatment levels to allow the return of product streams to the excavation site must be established at each site by the responsible agency or agencies. Nevertheless, since the use of remedial actions by treatment that " .... permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances" is strongly recommended (Section 121 of SARA), the THC Attrition Soil Washer System would appear to be an attractive candidate for consideration for remediation of sites contaminated with hydrophobic organic chemicals and/or heavy metals.

SARA also added a new criterion for assessing cleanups that includes consideration of potential contamination of the ambient air. This is in addition to general criteria requiring that remedies be protective of human health and the environment. Other than normal concerns for workers handling large volumes of contaminated soils and the dust generated during the excavation and movement of soil to the plant, there appears to be minimal opportunity for exposure by workers or neighbors to the contaminants. Since the soil washing is a wet process and all conveyors and process vessels are hooded and ventilated, exposure in the facility should be limited. The ventilating system for the plant will require treatment of the air prior to discharge. Air drawn from the bioslurry reactors does contain hydrocarbons from stripping action. The ventilating air collected from the soil wash plant also contains volatile organics and the metals treatment process requires treatment to control acid gases. Permits will be required for each of the emission points from the air treatment systems employed.

Additional regulatory aspects that might be addressed include permits for wells that might be drilled to treat groundwater (and provide water for soil processing) and any excavation authorization that may be necessary. Runoff from soil piles awaiting treatment may require treatment in systems that require permits. Depending on the size of the site being remediated and the roles of the bioslurry reactor, storage tanks may be necessary as reservoirs and to provide needed equalization. Such tanks may require permits, spill contingency plans, etc. depending on their size and whether they are above or below ground. For a large site and a large soil washer system processing as much as 55 tons/hour, water storage capacity would be large enough to require basins instead of tanks. This would raise additional regulatory questions about liners, secondary containment, leachate collection, etc.

Even if the overall process train achieves a condition whereby all water would be recycled during operation, discharge of the residual water and decontamination of all equipment will be necessary at the termination of operation. Depending on the contaminants present, this water may be suitable for direct discharge or discharged to a POTW with some treatment. A NPDES permit or sewer discharge permit would be required. While the SITE project is exempted from permit requirements under the Resource Conservation and Recovery Act of 1976 (RCRA), the Hazardous and Solid Waste Amendments of 1984 (HSWA), and state regulations, a commercial site will require a RCRA permit for the entire treatment system to operate as a hazardous waste treatment facility. This would include storage tanks, all treatment equipment/reactors, effluents, and if applicable, air emissions.

3.7 Materials Handling Requirements

Soil Excavation - The soil to be treated is excavated and transported to a covered shed prior to processing. The excavation and transport involve conventional earth moving equipment, such as front-end loaders and a dump truck.

Soil Washer - Materials handling is a significant labor and therefore cost factor for both the feed to the process, as well as the removal of solid product stream at the THC soil wash plant. The soil is removed from the storage shed utilizing a front-end loader and is then slowly fed to a vibratory grizzly. The soil drops to a belt conveyor that runs the soil to a rotating permanent magnetic separator. The output from this magnetic separator drops to a belt conveyor and constitutes the feed to the soil wash process. The sand product is conveyed by belt conveyors from the density separators to its product bin. The solid products are collected in three sided bins, which allows the periodic removal of the products using a small front-end loader. The coal/peat product is collected in a self-dumping hopper. The product solids are loaded into a dump truck and returned to the excavation site. Slurry product from the wash plant is pumped to the metals removal process or to the bioslurry reactor process depending on the nature of the contaminants.

The pilot facility materials handling was dictated by the need to maintain flexibility and meet space constraints. During the design phase of a full-scale facility project, significant materials handling changes would allow considerable savings.

Bioslurry Reactors - Material is moved from tank to tank utilizing diaphragm pumps. Material is discharged using permanently installed centrifugal pumps. The process was equipped with an automatic nutrient feeder operated by peristatic pumps, however the operator preferred to add the nutrients manually through ports on the top of the tanks. Filtered air for the aeration system is fed from a compressor located outside the building through a manifold to the bioslurry reactors.

Metals removal process - Material handling in the metals removal process involves pumping of slurries. The final product is a slurry that is either pumped to the bioslurry reactor process or returned to the excavation site after dewatering depending on the prior processing history of the soil and the contaminants originally present.

Fine Product Dewatering - The developer incorporated a system for dewatering using high pressure hydrocyclones to evaluate the performance of this technology that promised a considerable cost saving. The system was not successful in achieving meaningful dewatering of the fine soil product. As a result, the slurry product was returned by tank truck to the excavation site or pumped directly to the site if geography allowed. The developer will need to evaluate other dewatering processes such as sedimentation or other forms of filtration. The very fine particle size of the slurry may make this a difficult dewatering problem but an acceptable technology from mineral processing or sludge dewatering almost certainly can be found.

3.8 Personnel Issues

Soil Washer - The attrition soil washer evaluated as part of the soil recycling demonstration is automated in the sense that the material moves through the system without direct action by the operator. The wash plant itself is not labor intensive but does generally require the availability of two operators to monitor soil, slurry, and water flows and to make equipment adjustments and repairs as required.

The materials handling labor requirements for this unit are one front-end loader operator on a full-time basis to move soil to the soil washer to load the pretreatment grizzly and remove solid products from the plant.

The processing of soils with hazardous contaminants will demand a high level of attention to worker health and safety. The pilot unit has been provided with extensive hoods and ventilation to handle volatile organics released during the wash process and associated handling. In all cases, a comprehensive workplace and personnel health monitoring program tailored to the particular contaminants found in the soil being treated will be required. In general, worker contact with the feed or products is incidental to their work rather than routinely necessary.

Bioslurry Reactor Process - The bioslurry reactors utilize manually operated pumps for the transfer of slurries. There is little direct contact with the slurry in routine operation. A single operator, working half time on the bioslurry process and half time on the plants water treatment and management, is used on a one shift a day basis. If overflows from the reactors occur as a result of foaming, which has been encountered periodically, the operator is assisted by a general laborer in clean-up efforts. Spill response and clean-up must be appropriate for the particular hazards associated with the specific contaminants present in the soil being treated.

Metals Removal Process - The metals removal process is highly automated and incorporates modern computer monitoring and control. Direct contact by the operator with the process equipment or material is not routine. The process does require two full-time operators to make any adjustments that may be required as well as to initiate repairs and to respond to spills or other upsets. This process is a continuous process and runs well once equilibrium conditions are established. Therefore, by its nature it should be a round-the-clock operation and operators are required for 120 hour per week of operation. An additional operator may be required to handle periodic operation of the electrowinning process as well as support for the primary process.

This process utilizes acids and bases to effect the metals removal process. Routine contact with these materials or the soil being processed is not required. Personal protective clothing and gear is required for non-routine situations. Spill and emergency response plans and training are a necessity.

Section 4

Economic Analysis

4.1 Introduction

The primary purpose of this economic analysis is to provide cost information useful in understanding the likely costs of applying the THC treatment train at a production level of approximately 6.6 tons of dry soil feed per hour to the initial soil wash process. With this cost information and a knowledge of the basis for its development, it should be possible to develop cost estimates for other soil or production levels. An overall cost estimate for a plant with a soil feed rate of 55 ton per hour is also provided.

This economic analysis is based on assumptions and costs provided by THC or its contractors. This estimate is based on an analysis of costs incurred during the 9 months of plant operation experience accumulated in 1992. THC provided a cost analysis based on an assumption of 33 percent fines in the soil. This represents a worst case scenario for costs. Several other cases have been examined in order to highlight the importance of the amount of fines in the overall costs for the treatment train. The THC analysis was provided in Canadian dollars. We have converted to U.S. currency by using an exchange rate of $0.80 U.S. to $1.00 Canadian. Comments on the cost analysis and discussion of cost elements in general represent the author's engineering judgement. An effort has been made to present the cost analysis in a manner that will allow the reader to vary the basis to fit a particular situation or to evaluate the sensitivity of cost to a particular assumption.

Certain costs have not been included in this analysis because they would be site specific. These include plant site preparation, soil excavation, and transportation to the plant for treatment. The cost of disposal of the two waste products from the process have not been included because they will be site specific. The wastes involved are the coal/peat product and the metals recovered in the electrowinning used in the metals removal process.

Cost figures provided here are based on an analysis of the actual operation of the actual plant and actual personnel. The analysis involved identifying achievable long term production levels and utilizing actual cost experience to project costs when production is the primary goal of the operation.

4.2 Conclusions

- Based on an assumption of 33 percent fines and a 6.6 ton per hour dry solids feed rate, the estimated total cost for the THC treatment train is $220 per ton.

- The individual process costs on the same basis are:

Soil Washing:	$80/ton of soil treated.
Bioslurry Process:	$43/ton of soil feed.
Metals Removal:	$96/ton of soil feed.
TOTAL:	$219/ton of soil feed.

- Projected costs of a dedicated full scale 55 ton per hour of feed soil (33% fines) facility are:

Soil Wash	$ 43/ton
Bioslurry	23
Metals Removal	51
Total	$117/ton

- The projected costs for the pilot-scale unit are quite sensitive to the percentage of fines in the feed soil. This occurs because the bioslurry and metals removal processes are required to treat all the fine slurry. These process throughput rates therefore can limit the amount of time the wash plant can be operated. Assuming 16.5 percent fines, consistent with THC results for several soils, the total costs would drop to about $ 136/ton.

If 11 percent fines is assumed, the total costs are estimated at about $109/ton.

- The actual cost for a specific soil will also be a function of the relative difficulty in treatment in the bioslurry reactor system. The THC cost estimate is based on throughput rate that would result in a retention time in the reactors of about 10 days. If longer retention is required, more reactors will be required or the amount of time the soil wash process operates must be decreased.

- The actual cost for a specific soil will also be a function of the relative difficulty in treatment for metals removal. Soils with higher metals contamination levels may require lower throughput rates or multiple passes through the tubular contractor.

4.3 *Issues and Assumptions*

This section summarizes the major issues and assumptions used to evaluate the cost of the THC soil treatment process. In general, the assumptions are based on information provided by THC or its contractors. The basic cost information provided has been used in an analysis to illustrate the sensitivity of costs to the percent fines in the soil. The costs discussed are based on the experience developed during the first 9 months of 1992 during which the plant was operated for the THC demonstration. The process units used are the units included in the nominal 6.6 ton per hour of feed soil plant discussed. THC has also provided an overall estimate for a 55 ton/hour plant.

4.3.1 Waste Volumes and Site Size

The volume of soils that may require treatment at the Port Industrial District (PID) have been estimated at a level approaching 2,200,000 tons. For purposes of this analysis, a hypothetical case for a site that contains 22,000 tons of soil requiring remediation will be examined. Soil from the site is assumed to have a fines content of 16.5 percent and to contain contaminants which will require biological treatment and metals removal treatment. This case is developed in detail in Appendix D.

4.3.2 System Design and Performance Factors

The THC treatment train consists of three process units. Each of the process units has been designed so that the system consists of a number of trailer transportable modules. The individual processes are discussed below.

4.3.2.1 Soil Wash

The soil wash plant has a demonstrated throughput rate of about 6.6 tons per hour. At that rate it produces enough fine slurry to feed the 24 hour throughput of the metals removal process during an 8 hour shift, if the soil feed contains 33 percent fines. In the event the soil being processed contained about 16.5 percent fines, the wash plant could be operated for 16 hours per day, and, similarly, if the soil contained about 11 percent fines, the plant could be operated on a 24 hour basis and the metals removal process could be operated at a sufficient rate to maintain the fines production.

4.3.2.2 Bioslurry Process

The biological system has a total of 6 tanks with a total capacity of approximately 120,000 gallons. This includes 2 tanks normally used as feed hold tanks and one tank which was intended for digestion of the biomass. If all of these tanks are operated as batch bioslurry reactors, a detention time of about 10 days based on a rate of 475 gallons per hour is implied. If longer detention is required to treat either high contaminant levels or biologically refractory contaminants, then the capacity of the other plant processes will have to be reduced.

4.3.2.3 Metals Removal Process

The metals removal process appears to perform satisfactory when operating at a feed rate of about 475 gallons per hour of slurry with a solids content of about 24 percent by weight. This feed level results in the treatment of 0.56 tons per hour of solid on a dry basis. If contamination levels are such that high removal rates are not required, then higher throughput rates can be used. Conversely, if very high removals are required, a multiple pass configuration may be required with a resulting decrease in the throughput rates.

4.3.3 Manpower Requirements

The staffing levels required are presented in Table 6. The biological process operator manages the water in the plants collection and recirculation system in addition to the operation in the biological system. The maintenance mechanic monitors the air handling system and assists the process operators. in maintaining their systems. The maintenance mechanic is scheduled for the day shift. Routine preventative maintenance is performed by the operator at shift change. Major maintenance is performed on the soil washer on the off shift by using the operators on overtime. Labor rates were not provided by THC in their cost analysis. Instead, overall labor cost was provided with staffing information. A technical manager at one half time and a site manager and clerk as well as a scientist who provides sampling and data analysis service are allocated equally to the three processes in the total labor cost.

Table 6. Summary of Manpower Requirements THC Treatment Train.

	Per Shift	Total Per Day(1)
Attrition Soil Wash	2 Operators 1 Laborer	4 Operators 2 Laborers
Metals Removal	2 Operators	6 Operators
Biological Process	1 Operator	1 Operator
Maintenance	1 Mechanic	1 Mechanic
Site Supervision	1 Manager 1 Clerk	1 Manager 1 Clerk
Material Handling	2 Laborers	3 Laborers
Technical Supervision	0.5 Manager	0.5 Manager
Sampling & Analysis	1 Scientist	1 Scientist
		11 Operators 5 Laborers 1 Mechanic 1 Site Manager 1 Clerk 1 Scientist 1/2 Technical Manager

(1) Based upon operation of wash plant 16 hours per day and operation of metals removal and biological system 24 hours per day.

4.3.4 Financial Assumptions

For the purposes of this analysis, capital equipment costs are separated for the complete process units. Capital equipment costs were amortized over a 10 year period with no salvage value taken at the end of the period. An interest rate, to reflect the time-value of money was included by the developer. The interest rate used by the developer based on an analysis of the developer's data is 20%. The reader is cautioned that interest rates in Canada are considerably higher than in the U.S. at this time. However, it is clear that a return on capital is also included. Capital costs information supplied by THC is presented in Table 7.

Table 7. Capital Cost for THC Treatment Train.

Attrition Soil Wash	$1,200,000
Biological Treatment System	240,000
Metals Removal Process	800,00
Total	$2,240,000

4.4 Results

4.4.1 Remediation of Hypothetical Site

Table 8 shows the total cleanup cost for the hypothetical treatment of 22,000 tons of contaminated soil described in detail in Appendix D-1 in the existing THC Treatment Plant of $3,217,800. The remediation of this hypothetical site would require 229 operating days or just under one year to complete soil processing. The costs are also itemized by cost category and treatment process. The soil wash process accounts for about 50 percent of the total cost while the metals removal process accounts for about 35 percent of total cost and the biological treatment accounts for the remaining 15 percent. The soil wash process will process the entire 22,000 tons of feed while the other processes are required to treat only the contaminated fines, which, for our analysis, amounted to approximately 3650 tons. When considering the overall treatment train, the largest cost components are labor (56%), equipment costs (20%) and electrical energy (12%); consumables (10%) and analytical cost (3%) account for the remaining costs.

Based on the hypothetical case of 22,000 tons dry basis of contaminated soil treated, the total estimated unit cost is $147/ton; the breakdown of costs by technology is shown below.

	Unit Cost $/Ton
Attrition Soil Washer	73
Slurry Bioreactor Process	22
Metals Removal Process	52
Total	$147

These estimates do not include site preparation; permitting and startup costs. Cost for disposal or treatment of effluents and residuals also did not apply at this demonstration. One of the waste products, the coal/peat material may require disposal by incineration; and thus could represent a significant cost factor.

Table 8. Treatment Cost Summary for a Hypothetical Remediation of 22,000 tons of Soil with 16.5 Percent Fines and Both Organic and Inorganic Contaminants.

Cost Component	Soil Wash	%	Biological Treatment	%	Metals Removal	%	Total	%
1. Site Preparation Costs	N/A		N/A		N/A		N/A	
2. Permitting & Regulatory Costs	N/A		N/A		N/A		N/A	
3. Equipment Costs	$317,300	20	$71,100	15	$246,900	22	$635.300	20
4. Startup	N/A		N/A		N/A		N/A	
5. Labor	$872,300	55	$259,800	54	$656,900	57	$1,789,000	56
6. Consumables & Supplies								
Chemicals	$66,800	4	$26,800	6	$100,000	9	$193,600	6
Maintenance Supplies	$53,400	3	$13,800	3	$43,400	4	$110,600	3
7. Utilities								
Electric	$233,200	15	$83,400	17	$66,800	6	$383,400	12
8. Effluent Treatment & Disposal	N/A		N/A		N/A		N/A	
9. Residuals/Waste Shipping, Handling & Transport Cost	N/A		N/A		N/A		N/A	
10. Analytical Costs	$53,200	3	$26,800	6	$26,800	2	$106,800	3
11. Facility Modification, Repair & Replace	N/A		N/A		N/A		N/A	
12. Demobilization Cost	0		0		0		0	
Total	$1,596,200	100%	$481,700	100%	$1,140,800	100%	$3,218,700	100%
Cost/Ton	$72.55		$21.90		$51.85		$146.30	

4.4.2 Sensitivity of Costs to Fines Content of Soil

The hypothetical case cost estimate is based on a fines content of 16.5 percent. The estimated cost per ton is quite sensitive to the percent of fines present. This occurs because the metals removal and or biological treatment capacity can limit the utilization rate of the wash plant.

If the feed soil contains 33 percent fines, the wash plant would be operated 40 hours per week to support the operation of the metals removal process for 120 hours per week. Similarly, at 16.5 percent fines the wash plant could be operated 80 hours per week and at 11 percent fines the wash plant could be operated for 120 hours per week.

Cost estimates for these cases are summarized below.

	Cost $/ton of feed soil		
	33% Fines	16.5% Fines	11% Fines
Attrition Soil Process	80	67	63
Biological Treatment	43	21	14
Metals Removal Process	96	48	32
Total	219	136	109

These cost estimates do not have any allowance for operating downtime other than that already built into the THC analysis. The cost in the hypothetical case study provides for an additional 10 percent downtime.

The metals removal process and the biological treatment system are only required to process the fine slurry. The cost of operating these processes at the nominal 0.73 ton/hour process rates for fines are:

	Unit Cost $/Ton Actually Processed
Biological Treatment Process	128
Metals Removal Process	287

4.4.3 Other Limitations of Cost Analysis

The reader is cautioned that the costs accounted for in this analysis do not include some site specific elements that could significantly effect final costs. In addition capital and operating cost for an appropriate dewatering process must also be included. THC has assumed an operating throughput rate for the metals removal process somewhat higher than those observed during the demonstration. The relatively long process times for the bioslurry reactor process actually used during the demonstration would result in the cost estimate given for the biological process being low. If retentions of 30 to 40 days as observed are required, the biological process cost could increase by a factor of 3 to 4. Careful treatability experiments will be required to refine cost estimates.

The developer has included the costs of the ion exchange chelating resin in the capital cost of the facility. If the chelating resin must be replaced before the 10 year life assumed, or replenished, a significant additional cost could be incurred. Data on the expected life of the chelating resin has not been developed at this time.

4.5 Full Scale (55 Ton/Hour) Facility

THC has provided a cost estimate for a facility that would process 55 tons per hour on a dry weight basis of feed soil on a continuous basis. The general scale-up assumptions are discussed by process below.

Soil Washing - The 55 ton/hr plant would employ a scaled-up wash plant that would be operated on a continuous basis. A single large process unit is planned. Improvement in materials handling for the feed and product solids such as transportable product hoppers, would be employed, to return soil to the excavation site. Operator labor is expected to remain almost the same as with the 6.6 ton/hr plant. A full time mechanic would be assigned to each shift.

Biological Treatment System - The scaled-up plant would utilize bioreactors of increased diameter and thus achieve greatly increased capacity. Transfer and nutrient additions could be automated so that only minimal operator input is required.

Metals Removal Process - The scaled-up plant would utilize somewhat scaled up process units but multiple units still will be required. The high level of automation and computer control are expected to allow continued operation with two operators per shift supported by the availability of the mechanic mentioned above.

The THC cost estimates for this facility are given below.

	Treatment Cost $/Ton of Feed Soil
Attrition Soil Wash	43
Biological Treatment Process	23
Metals Removal Process	51
Total	$117

These estimates are based on the discussion above and the use of a scaling algorithm by THC and they are not as reliable as the costs discussed for the existing system.

Appendix A

Process Description of THC Soil Recycling Treatment Train

The overall project includes the evaluation of a high pressure soil wash process and an attrition wash process integrated with the metals removal process and a bioslurry reactor. The treatment facilities are enclosed in a temporary building approximately 90 feet wide, 200 feet long and 40 feet high. The SITE demonstration focused on the treatment of soil from a refinery site in the PID.

The THC, through its contractor, excavated approximately 1040 tons of the top 6 feet of this soil using a front-end loader. The soil was transported to an enclosed storage building at the test facility. The soil was fed to the treatment plant at a rate of about 6.6 tons per hour. The feed process consists of using a front-end loader to move the soil from the storage building and dumping it onto a vibratory grizzly with 1.97 inch openings. The output of the grizzly is then run over a rotating permanent type magnetic separator to remove tramp iron. The material leaving the magnetic separator is then fed to the attrition wash plant by conveyor. THC is simply putting the rejects from the grizzly and the tramp iron aside during this demonstration. This is, therefore, considered a pre-treatment and was not sampled as part of this program. When a full-scale plant is designed, the material separated in the pre-treatment would be washed with a spray device and then be recycled as scrap iron, or, in the case of the plus 1.97 inch debris (concrete, bricks, etc.), will be crushed for return to the soil site from which it came.

A.1 Attrition Soil Washing

Soil washing is the first of the technologies in the integrated treatment train. Because the large majority of contaminated soils encountered at the PID are sandy, silty soils, soil washing is an economical and effective process to separate contaminants from the bulk of the soil. The soil washing method used during the demonstration uses scrubbing action and selected chemicals to separate contaminants from the larger soil particles. The rotary trommel washer removes particles larger than 0.24 inch as a gravel fraction. The contaminated <0.24 inch soil and washwater pass through the screen in the trommel washer into a holding tank where belt-type oil skimmers remove free oil from the water. The remaining soil and washwater are pumped through a separation hydrocyclone where the contaminated fines (less than 0.0025 inch) are separated from the coarser soil particles. Larger sand particles are easily separated from the fines where the contaminants are concentrated. The fines are pumped to a lamellar separator and then to a gravity thickener, while the coarse sand is pumped to the attrition scrubbers.

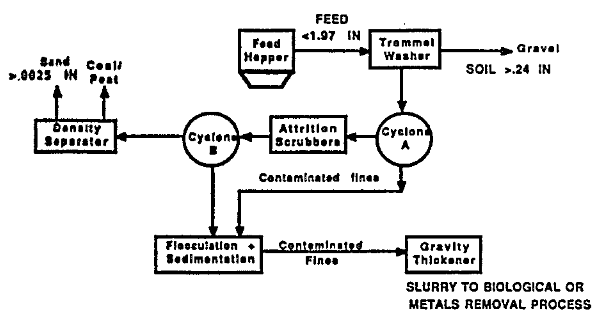
There are three attrition scrubbing cells that act to agitate the soil particles, causing them to rub against each other and scrub the fine particles and contaminants off the surfaces of the soil particles. The slurry of the soil and washwater is scrubbed in the first cell, then pumped to the second cell for further scrubbing, and then pumped to the third cell for final scrubbing. Potentially, detergents or surfactants may be added to the third cell and acids or bases, if required, to aid in dislodging contaminants from the soil particles or in dissolving certain contaminants. The treatment processes subsequently used to treat the contaminated slurry restrict the types of chemicals which can be used in this treatment train.

Scrubbed particles and washwater from the attrition scrubbing units are pumped to a second hydrocyclone at the top of the plant, where sand particles (>0.0025 inch) are separated from the process water and the remaining fines. The sand stream from this separator is then put through a density separator to remove the light materials, such as coal, wood, and peat particles from the heavier soil particles. The coal and peat are collected separately, as a potentially contaminated waste stream. The sand is discharged by conveyor to a collection bin and is combined with the gravel from the trommel washer for return to the original site. This "clean" material is expected to include approximately 70 to 80 percent of the soil feed to the wash plant.

Contaminated fines with a grain size smaller than 0.0025 inch, pass through the lamellar separator and sludge thickener to remove water. The contaminated slurry from the sludge thickener is fed into two large holding tanks at the front end of the metals removal system or directly to the bioslurry reactor process. The contaminated slurry is expected to represent approximately 15 to 30 percent of the soil feed to the wash plant.

The contaminated process water removed by the lamellar separator and sludge thickener is discharged to an outdoor storage pond for recycle. Any sludge recovered from the ponds is then added to the deep cone sludge thickener where it joins the slurry for further treatment. The soil washing flow diagram is shown in Figure A-1.

FIGURE A-1
SIMPLIFIED PROCESS FLOW DIAGRAM FOR SOIL WASH PROCESS



A.2 Biological Treatment System

The biological treatment technology being evaluated is referred to as the Bioslurry Reactor Process. This process involves a series of reactors (tanks) where organic contaminants are treated. Prior to the introduction to the reactor, the slurry is pretreated with a proprietary inorganic oxidant.

The slurry awaiting treatment of its organic contaminants is gently mixed in two surge tanks to promote contact between the contaminants and the oxidant. The slurry is then pumped to one of three 20,000 gallon upflow bioreactor tanks normally used in pilot operation. Submerged pumps and the upflow of air for the medium to fine bubble aerators provide constant mixing conditions and the suspension of fines.

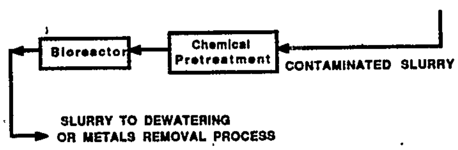
The biological system is prepared by culturing a bacteria population from the bacteria that have developed in the soil on-site. This is accomplished by pumping a limited amount of fine slurry obtained from the soil wash process directly to the bioreactors without passing through the metals extraction process where the highly acidic conditions would destroy the desired bacteria. This allows the development of a bacterial population in the bioreactor based on strains in the soil to be treated. Fine slurry is accumulated until a single reactor is fully charged.

Nutrients in the form of urea and phosphoric acid solutions are added periodically. In addition, periodic additions of oxidant may be made.

The final slurry is dewatered once the organics content in the slurry is reduced to a target level, or no further bio-reduction is occurring, as indicated by periodic sampling and analysis. During this study the slurry was returned to the excavation site without dewatering because the high pressure cyclone dewatering system employed was not able to achieve meaningful dewatering.

The biological treatment process is shown in Figure A-2.

FIGURE A-2
SIMPLIFIED FLOW DIAGRAM
BIOSLURRY REACTOR PROCESS



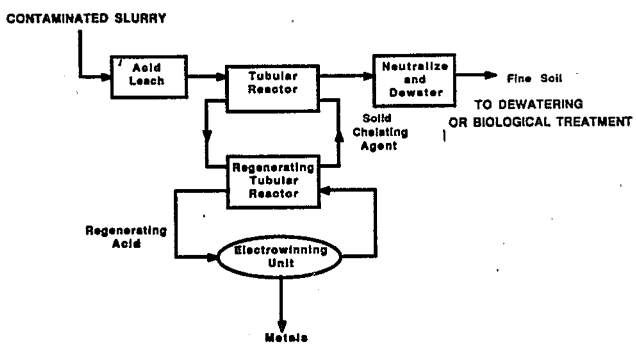
A.3 Metals Removal Process

The contaminated slurry from the attrition wash plant or the bioslurry reactor process is fed into two large holding tanks in the central area of the facility, at the front end of the metals removal process. The slurry consists of approximately 24% solids by weight and 76% process water. Mild acid is added to the slurry from the acid storage tanks to desorb and solubilize any metal contaminants from the soil particles. The identity of the acids used has not been disclosed.

The contaminated slurry is then pumped into the first tubular reactor. This screw-type rotary reactor brings the slurry into countercurrent contact with solid metals chelating agents that have an affinity for specific metal contaminants. From here, the slurry, which now contains only soil particles, organic contaminants, residual metals not removed by the process, and process water, is pumped to a holding tank, where it is neutralized.

The solid chelating agent, which moves countercurrent to the slurry, now contains the extracted metals. The solid chelating material is selected from a family of metals specific ion exchange chelating resins to preferentially remove heavy metals. It is washed to remove solid soil particles and is fed through a second tubular reactor where a mild acid is used to break the bond between the chelating agent and the contaminant metals. The chelating agent is then recycled to the first reactor for reuse in the metals extraction process. Meanwhile, the metal/acid mixture is recycled in the second reactor until it becomes sufficiently rich in metals to be pumped to an electrowinning unit, where the metals are then removed by electrolysis. The result of the build-up of metal concentration in the regenerating acid will be some reduction in the absorption capacity of the resin beads being returned to the slurry contactor, however the system has been designed to provide excess absorption capacity of the chelating resin in relationship to the metals being absorbed. Little change in performance is expected. Another, more long term deterioration of the resins absorption capacity is associated with the oxidation of the active sites on the resin bead. This is expected to be a reaction measured in months to years and should not effect this demonstration. Nevertheless, resin replacement costs can be a significant cost factor in such a system. The metals may be removed singly or as one composite mass. During the electrowinning the metals-depleted acid is then pumped back to the holding tanks either for reuse as regenerating acid or it may be neutralized and become a part of contaminated slurry. The metals extraction process is shown schematically in Figure A-3.

FIGURE A-3
SIMPLIFIED PROCESS FLOW DIAGRAM
METALS REMOVAL PROCESS



A.4 Water Use

The facility was designed with an integrated water recycle scheme. The site was graded and paved to collect all precipitation in lined ponds which would supply water for the operation. The design called for minimal discharge of water primarily because considerable water was expected to leave the plant with the clean soil fractions. The design also provided for a process water pond that would receive water from the wash plant and the water separated from the final treated slurry. The process pond would recycle water for use in the soil wash plant and for ion exchange resin bead washing in the metals extraction process. Approximately 60 percent of the water in the tested fines is recovered and recycled. During the THC demonstration excess water was accumulated at times due to heavy rainfall. This water was treated prior to discharge to the sanitary sewer.

Water can be pumped from Lake Ontario to use for make-up during periods in which make-up water was required.

A.5 Air Supply and Emissions Control

The air for the bioslurry reactors is taken in through two intake units, filtered, and pumped to the bioslurry reactors. It is then exhausted into an air treatment system consisting of two biofilters and a carbon adsorption unit. Power for drawing the air from the bioslurry reactors through the biofilters is provided by one of two 5,000 cfm pumps.

Air collected from the metals removal process is passed through a caustic scrubber unit to remove any acid that might otherwise be taken into the biofilters. The air stream results from maintaining a slight negative pressure on all tanks and reactors which contain acid. In addition, both tubular reactors are open to the atmosphere to allow feed of materials. The ends of the reactor are hooded to collect any acid gases so that they do not cause health or safety problems in the work area. The acid removed is either recycled or is neutralized and discharged to a holding tank as an addition to the slurry. The air itself is then passed through the common system of biofilters.

The "biofilters" consist of modules 10 x by 10 ft x 40 ft. The module is filled with peat. The air is introduced into a perforated pipe distribution system on the floor of the module. These filters are expected to provide adsorption of organics and continuing biological activity under summer conditions to consume the material adsorbed. Under the cold conditions actually experienced during the demonstration, biological activity is unlikely, but the elimination of any mists or particles is expected then when the warm temperatures occur in the summer this adsorbed material undergoes biodegradation. The air is collected from the air space at the top of the module and routed to the final 10 ft x 10 ft x 20 ft activated carbon filter. Air exhausted from the activated carbon filter is discharged through a 39 foot high stack. The developer reports that no measurable contaminant emissions were ever detected leaving the biofilters. The absence of organic contaminants upon analysis of the carbon, in the carbon filter following the biofilters, at the end of the 9-month project has confirmed that all volatile hydrocarbons were retained and actively biodegraded within the biofilters. In a full scale plant requiring year-round biodegradation in the biofilters the biofilters could be heated to promote biodegradation. This capability was available for the demonstration project but heating the biofilters never became necessary.

Air is collected from the conveyors and open tanks in the soil wash area by enclosing these areas with hoods and shrouds. This air is drawn through an activated carbon filter by one of the 5000 cfm fans and mixes with air drawn off the metals removal and biological systems for treatment in the common biological filter system and final activated carbon filter before discharge through the common stack.

Appendix B

Vendor's Claims

The THC demonstration was conducted to evaluate the ability of an integrated soil treatment train, which includes a soil washing process, a biological treatment process, and a metals removal process to treat contaminated soils so that the treated soil meets target criteria for proposed land use applicable to soils for commercial/industrial sites. The criteria have been developed by THC by combining existing criteria for conventional pollutants and metals with a site specific criteria developed for a contaminated soil associated with a refinery site. Collectively, these criteria are referred to as the THC Criteria.

The THC claims the technology will meet the following performance criteria.

1. Produce the following soil fractions from the soil washer, each of which will meet the THC Target criteria for coarse textured soils described in Table B-1 for both organic and inorganic compounds independent of the soils initial contaminant levels.

   A. Clean gravel (less than 1.97 in; greater than 0.24 inch).
   B. Clean sand (less than 0.24 in; greater than 0.0025 inch).

2. Produce a fine soil fraction (less than 0.0025 in) after metals removal and/or biological treatment which will meet the THC Target criteria for fine textured soils described in Table B-1 for both organic and inorganic compounds independent of the soil's initial contaminant levels.

Table B-1. THC Target Criteria for Soils for Commercial/Industrial Land Use

Parameter	Coarse Textured Soil[1]	Medium and Fine Textured Soil
Conventional		
pH (recommended range)	6-8	6-8
Oil and Grease (%)	1	1
Total Metals (Units mg/kg)		
Arsenic	40	50
Barium	1500	2000
Cadmium	6	8
Chromium (total)	750	1000
Cobalt	80	100
Copper	225	300
Lead	750	1000
Mercury	1.5	2
Molybdenum	40	40
Nickel	150	200
Selenium	10	10
Silver	40	50
Zinc	600	800
Organic Compounds (Units mg/kg)		
Naphthalene	(8.0)[3]	(8.0)[3]
Phenanthrene	(28.0)[3]	(28.0)[3]
Anthracene	(12.0)[3]	(12.0)[3]
Fluoranthene	30[2]	30[2]
Pyrene	(48)[3]	(48)[3]
Benzo(a)anthracene	(15.8)[3]	(15.8)[3]
Chrysene	(28)[3]	(28)[3]
Benzo(b)fluoranthene	(2.4)[3]	(2.4)[3]
Benzo(k)fluoranthene	13.2[2]	13.2[2]
Benzo(a)pyrene	2.4[2]	2.4[2]
Benzo(a,h)anthracene	1.8[2]	1.8[2]

1. Defined as greater than 70% sand and less than 17% organic matter.
2. Clean-up levels are shown for organic compounds. If soils exceed these levels, then the soil is considered hazardous and remediation is required.
3. If these trigger levels are exceeded, the THC will make a determination on a case by case basis regarding the need for remediation.

Appendix C

Site Demonstration
Soil Recycling Treatment Train
The Toronto Harbour Commissioners

C.1 Introduction

The Toronto Harbour Commissioners (THC) have developed a soil treatment train designed to treat inorganic and organic contaminants in soils. THC has conducted a large-scale demonstration of these technologies in an attempt to establish that contaminated soils at the Toronto Port Industrial District can be treated to attain contaminant levels below the THC Target Criteria Levels for Industrial Soils without utilizing incineration processes. This Superfund Innovative Technology Evaluation (SITE) of the on-going THC Demonstration was undertaken to provide a consistent basis for comparing these technologies to other technologies evaluated under the SITE program.

C.2 Feed Characteristics and Variability

C.2.1 General

The soil processed during the SITE evaluation was designated as Soil B by THC. It was excavated from a site immediately adjacent to the process plant. Characterization of the site and limited predemonstration sampling conducted in early 1992 indicated that the soil exhibited relatively high organic and inorganic contamination. When large volumes of the soil were excavated and processing initiated, the inorganic contamination levels were found to be quite low. Another long term variation in the soils composition was noted in the under 1.97 inch, greater than 0.24 inch fraction removed by the trommel washer. During a presampling visit and familiarization sampling early in the soil run this fraction was relatively minor in volume and was largely pebble-like material not much over the 0.24 inch in size. When sampling was conducted, this fraction accounted for approximately 10 percent of the feed mass and included relatively large coal and wood fragments as well as much larger smooth (river gravel-like) pebbles. As a result of the appearance of this fraction, the analytical extraction procedure was modified and an approach for separating these large particles from the feed soil and extracting them separately in bulk was also adopted.

C.2.2 SITE Sampling

During the course of the three day sampling event, four hour composite samples were accumulated by hourly grab sampling of the feed soil from the conveyor that feeds the wash plant trommel washer. Therefore, each day two composite samples were taken during the normal 8 hours of wash plant operation. The composite samples were analyzed for the following characteristics: O&G (oil and grease), TRPH (Total Recoverable Petroleum Hydrocarbons), SVOC (Semi Volatile Organic Compounds), total metals, mercury, total cyanide, reactive sulfide, PSD, (Particle Size Distribution), pH and % moisture. The total metals and SVOC analyses call for the extraction of several grams of sample. The presence of the relatively large "rocks" in the feed led to a modification of the procedure for these analyses. The samples were separated into a "soil" fraction and a "rock" fraction using a number 4 sieve. The soil was extracted using the usual 2 gram sample while the entire "rock" fraction from a 500 ml sampling bottle was extracted without crushing the "rock".

Table C-1 presents the results of these analyses for selected parameters. The feed soil appears to just exceed the THC Target Criterion for naphthalene and to just approach the criterion level for oil and grease and benzo(a)pyrene. The conventional parameters (pH, % moisture, O&G and TRPH) exhibit moderate variability while the metals and the two PAH compounds of interest exhibit considerable variability. A comparison of the data for the soil and "rock" fraction

TABLE C-1. CONCENTRATION OF SELECTED PARAMETERS IN THE FEED SOIL THC ATTRITION SOIL WASH PROCESS

Soil	THC Criteria	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average	Standard Deviation
pH	6-8	8.49	8.59	8.69	8.28	8.17	8.22		
% Moisture	---	7.49	8.51	7.53	9.07	12.6	9.88	9.18	1.91
Oil & Grease mg/kg	10,000	7800	6700	9000	8100	9700	8100	8200	1030
TRPH mg/kg	---	2270	2700	3250	3430	2550	2040	2540	416
Cu mg/kg	225	9.2	12.3	9.9	15.4	20.6	42.2	18.3	12.4
Pb mg/kg	750	106	63.3	68.4	97.4	177	177	115	50.8
Zn mg/kg	600	40.4	56.6	40.9	83.5	92.8	181	72.5	52.9
Naphthalene mg/kg	8.0[2]	15	7.7	18.0	13.0	8.0	5.3	11.15	4.9
Benzo(a)pyrene mg/kg	2.4	(1.6)[1]	(0.93)	(1.7)	2.9	(2.5)	(1.9)	(1.92)	(0.7)
Rocks									
Cu mg/kg	225	4.3	6.8	20.5	19.6	24.7	34.9	18.45	11.4
Pb mg/kg	750	26.4	93.7	112	114	195	175	119	60.3
Zn mg/kg	600	19.3	28.3	94.3	72.7	219	211	107	87.8
Naphthalene mg/kg	8.0[2]	7.6	6.6	16.0	5.1	8.8	16.0	10.0	4.8
Benzo(a)pyrene mg/kg	2.4	(1.1)	(0.55)	(1.1)	(1.2)	2.2	4.4	(1.76)	(1.4)

1. ( ) Indicates value reported is below quantitation limit but above detection limit. Value should be considered an estimate.
2. If these trigger levels are exceeded, the MOE will make a determination on a case by case basis regarding the need for further remediation.

indicates the two fractions are equivalent for the metal and PAH compounds examined.

C.3 Attrition Soil Wash Process

C.3.1 Feed

The feed soil discussed for the overall process is the feed soil for the attrition wash process.

C.3.2 Products

C.3.2.1 Gravel (Through 1.97 inch, greater than 0.24 inch)

This product is produced by the trommel washer, which removes material smaller than 0.24 inch from the coarse material. THC estimated this fraction as 10.5 percent of the feed on a dry basis. Data collected during the SITE sampling indicated that this product accounted for 11.5 percent of the feed on a dry weight basis. Considering the limitation on the estimating technique used, this would appear to be excellent agreement. During the three day sampling event, six composite samples were developed by compositing four hourly grabs. This resulted in two 4 hour composites for each day of operation. Each of these composites was analyzed for the same group of parameters listed for the feed samples. SVOC and total metals extractions were performed on bulk samples without sample crushing.

Table C-2 presents analytical results for selected parameters for these samples. The average values reported meet all the THC Target criteria for coarse soils. An examination of this data indicates that Sample No. 6 exhibited higher oil and grease contamination and very much higher (10 times or more) heavy metals contamination than for the other samples. TRPH and PAH values did not exhibit the same behaviors. The sample team had noted that this product stream had become very dirty during the course of the third day of sampling and appeared to be coated with an oily paste of fines. An examination of feed soil data for the same time frame (Sample No. 6 Table 1) shows this same tendency but not nearly as dramatically as does "clean gravel" Sample No. 6. If the data are excluded, it results in a dramatic drop in the average as well as the standard deviation. Sample No. 6 appears to be from a different population than the other five samples; since it appeared visually to be contaminated, the analytical results should not be suspect. Possible explanation centers around two possibilities.

1. During the third sample day it was raining steadily. The soil is fed to the grizzly by slowly dumping the contents of the front end loader bucket onto the grizzly. The grizzly is located outside of the building so the soil was exposed to the rain for the period of 8 to 10 minutes required to feed the material slowly. This may have caused fines and oil material to concentrate on the large gravel in such a manner that it was difficult to remove in the trommel washer.

2. Soil had been moved from the excavation site to an enclosed shed for drying and to facilitate feed operations. It is possible that some migration of oily fine contaminated materials caused a concentration of these materials in the bottom areas of the storage piles. The material being fed during this sample may have contained more of this material than normal because the loader was raking the bottom of depleted piles.

There is no proof that either explanation is valid but the second hypothesis appears to be more sound.

Table C-2. THC Attrition Soil Wash Process Concentration of Selected Parameters in Gravel <1.97in.; >0.24in.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average	Standard Deviation
Oil & Grease mg/kg	1200	1900	1300	1800	3400	10400	3333	3550
TRPH mg/kg	269	579	543	1481	1571	443	814	562
Cu mg/kg	.72	7.57	1.84	9.8	12.1	52.1	14.0	19.2
Pb mg/kg	3.22	56	9.84	117	40.4	702	155	271
Zn mg/kg	2.26	36.1	7.6	85.5	98.6	544	129	207
Naphthalene	2.9	2.1	1.8	1.3	2.8	3.8	2.5	896
Benzo(a)pyrene	(700)[2]	(380)	(170)	(250)	990	1000	(582)	368
pH	8.79	8.82	8.68	8.62	8.43	9.11	8.74	0.23
% Moisture	7.48	10.29	3.00	6.47	8.43	7.38	7.18	2.4

1 Values of $\overline{X}$ and SX calculated without data from composite sample No. 6.

2 Indicates value reported is below quantitation limit but above detection limit. Value should be considered an estimate.

Since the contamination level in the "clean gravel" was visible by inspection, it would be possible in practice to recycle this material to the feed and reprocess it. In addition, the sample only exceeded the THC Target Criterion for oil and grease by a slight amount and would have met all other criteria. In subsequent analysis of the data, data from Sample No. 6 were excluded for the three metal parameters where the results deviated most from the prior samples. This anomalous behavior may be important if the soil to be treated is very high in oil and grease contents. In such cases, the use of surfactants may be a necessity, or, alternately, modification of the trommel washer may be required.

C.3.2.2 Sand (Through 0.24 inch; greater than 0.0025 inch)

The sand product is separated from the fines in the soil by utilizing a hydrocyclone classifier. The nominal cut point for this classification is reported to be 0.0025 inch. The coarse cut from the classification is passed over a vibratory sieve that dewaters and removes low density particles (coal & wood fragments, peat).

THC reported that this fraction accounted for 70.2 percent of the feed on a dry basis. Data collected during the three days of SITE sampling indicated 68.1 percent of feed on a dry basis for this product.

Once again composite samples were obtained in the same manner as the feed and gravel and analyzed for the same parameters.

Table C-3 presents the analytical results. The average values and the individual composite data all meet the THC Criteria for fine soil.

Metals levels for Samples No. 5 and 6 appear higher than the prior two days' samples but do not exhibit the wide departure seen in Sample No. 6 for the clean gravel fraction.

C.3.2.3 Coal/Peat Waste (Through 0.24 inch, greater than 0.0025 inch)

Coal/peat waste is separated from the clean sand fraction using a vibratory dewatering screen. The lighter particles are vibrated up a screen to separate them from the heavier soil particles. This stream is expected by THC to be a waste product that they hope to find a use for as boiler fuel. It is predominantly coal particles and fragments of wood in various stages of decay. THC reported about 2.5 percent of the feed on a dry basis reports to this waste product. SITE sampling found 1.6 percent of the feed on a dry basis reporting to this fraction. A single composite sample for each day of sampling was accumulated by taking a grab sample every two hours during the course of a normal 8 hour operating day. The samples were submitted for analysis for oil & grease, TRPH, SVOC and total metals. Table C-4 presents the analytical results for these samples. This waste exceeds the THC Target criteria for oil and grease, also naphthalene and benzo(a)pyrene.

C.3.2.4 Contaminated Fines (Less than 0.0025 inch)

The fines separated from the coarse soil particles by the classifying cyclones are treated with a flocculent to aid settling and are accumulated in a slurry underflow from an inclined plate settling tank. The slurry is transferred continuously to a deep cone settling tank, which was to be used for further concentration of the solids but is being used simply as a holding tank. THC reports the approximate solid content of the slurry is 24 percent by weight. An estimate of the solids content for the SITE sampling period based on mass balance information and estimated volume of slurry produced is 34 percent solids. An estimate of the solids content based on calculations using moisture content levels in the samples of contaminated slurry leads to a 33 percent solid by weight estimate. It therefore appears that the 33-34 percent solid level is most representative for our sampling period.

THC reports an overall estimate for this product of 16.7 percent of the feed on a dry basis. Data collected during the SITE sampling resulted in an estimate of 18.8 percent of the feed on a dry basis for this product stream.

The contaminated slurry was sampled by combining four hourly grabs into a composite sample. This produced two composites per day for each of the three days of sampling. The samples were analyzed for the same parameters as the other fractions. The results of these analyses are presented in Table C-5. They indicate the contaminated fines exceed the THC criteria for O&G, naphthalene and benzo(a)pyrene.

C.3.2.5 Waste Water Streams

The wash water utilized in the THC attrition wash process is recycled from a holding pond located adjacent to the building. A grab sample of the pond waste water was obtained on the first and third day of sampling in the area near the intake for the recycle pump. The samples were analyzed for the primary parameters being tracked in the soil. Table C-6 presents the results of these analyses for selected parameters. In general, it appears that the

Table C-3. THC Attrition Soil Wash Process Concentration of Selected Parameters in Clean Sand <0.24 in.; >0.0025in.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average	Standard Deviation
Oil & Grease mg/kg	1,500	1,400	1,500	2,500	2,300	3,900	2,183	960
TRPH mg/kg	561	383	684	731	561	963	647	196
Cu mg/kg	3.6	3.1	4.6	6.3	32.7	32.4	13.8	14.6
Pb mg/kg	27.9	42.4	23.6	31.0	82.9	68.4	46.0	24.2
Zn mg/kg	15.9	18.5	20.1	31.4	71.4	47.5	34.1	21.7
Naphthalene mg/kg	1.5	1.5	2.0	2.3	3.1	1.9	2.050	599
Benzo(a)pyrene mg/kg	(0.24)[1]	(0.57)	(0.24)	(0.50)	1.20	(0.41)	(0.53)	356
pH	9.01	8.38	8.06	8.95	8.51	8.33		

1 () Indicates value reported is below the quantitation but above the detection limit. Value reported should be considered an estimate.

Table C-4. THC Attrition Soil Wash Process Concentration of Selected Parameters in Coal/Peat Waste

	Sample 1	Sample 2	Sample 3	Average	Standard Deviation
Oil & Grease mg/kg	17,600	45,200	51,600	38,100	18,070
TRPH mg/kg	4,740	16,200	14,600	11,850	6,210
Cu mg/kg	22.8	34.1	41.7	32.9	9.5
Pb mg/kg	129	339	749	406	315
Zn mg/kg	46.8	176	406	210	182
Naphthalene mg/kg	34.0	110.0	48.0	64.0	40.45
Benzo(a)pyrene mg/kg	(11.0)[1]	(23.0)	(9.6)	(14.5)	7.4

1 () Indicates value is below quantitation limit for procedure. Value shown is estimated.

Table C-5. THC Attrition Soil Wash Process Concentration of Selected Parameters in Contaminated Fines <0.0025 inch

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average	Standard Deviation
Oil & Grease mg/kg	40,000	33,300	50,500	54,300	35,300	26,900	40,000	10,520
TRPH mg/kg	12,300	8,500	19,800	18,100	13,600	12,200	14,080	4,170
Cu mg/kg	57.4	48.2	76	--(1)	135	99	83.1	34.9
Pb mg/kg	421	334	525	--(1)	680	651	522	148
Zn mg/kg	217	192	250	--(1)	593	467	344	177
Naphthalene mg/kg	49.0	52.0	82.0	45.0	65.0	(17.0)	51.7	21.7
Benzo(a)pyrene mg/kg	(9.0)(2)	<32.0	(9.6)	(11.0)	(12.0)	(8.4)	(10.0)	11.5

1 Sample bottle broken in shipping.
2 () Indicates value is below quantitation limit for procedure. Value shown is estimated.

contaminants of interest do not partition to the waste water stream for this soil.

Table C-6. Selected Characteristics of Water Recycled to THC Attrition Wash Process

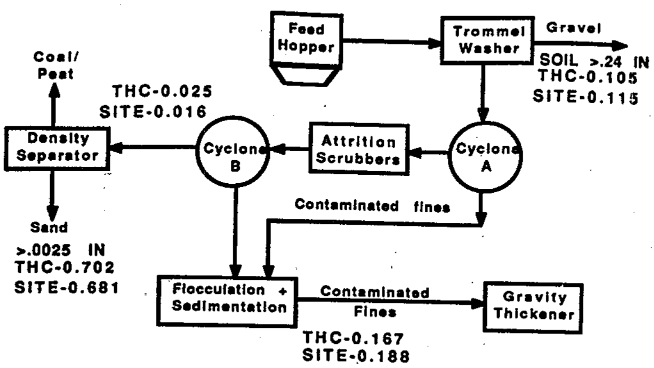
	Day 1	Day 3
Oil & Grease mg/l	<5	<5
TRPH mg/l	<.44	1.15
Cu ug/l	(12)	11
Pb ug/l	<21	(50)
Zn ug/l	61	46
Naphthalene ug/l	<10	<10
Benzo(a)pyrene ug/l	<10	<10

C.3.3 Mass Balance

Overall Soil B Run:

THC provided a summary of their overall run on Soil B. A summary of that data is presented in Figure C-1.

FIGURE C-1
SIMPLIFIED PROCESS FLOW DIAGRAM FOR SOIL WASH PROCESS SHOWING PRODUCT FRACTIONS ON A WEIGHT BASIS



C.3.3.1 Site Demonstration Sampling

A mass balance was calculated for the period during which the SITE sampling occurred. This data is also summarized in Figure C-1.

C.3.3.2 Discussion of Mass Balance Results

The mass balance is based on an engineering approach to estimate the mass balance when the volume of materials being handled and an existing plant configuration preclude actual measurements. The approach involved counting the number of front end loader buckets of feed and products each day, measuring volumes and bulk densities of feed and products periodically, and using this information to estimate the mass balance of solids. The slurry solids are estimated by the difference between the feed and product solids. Considering these limitations, the overall THC estimate and that developed for the SITE sampling time period agree quite well. Determining slurry solids by difference is a weakness in this approach. Water sampling data does suggest little loss to the wash water.

C.3.4 Discussion of Soil Wash Process Results

Table C-7 presents a summary of the data from analytical results for the individual feed and product stream. The values presented are the averages for the composite samples. The data for the feed soil were used without adjustment for "rocks" since the data suggested no such adjustment was needed. The trommel oversize fraction metals data are based on the averages of 5 composites with metals data from the sixth sample excluded as discussed earlier. The percent recovery columns on the right were calculated by summation of the mass of each constituent accounted for in each product stream and dividing by the mass of the constituent in the feed soil. That is:

$$\% \text{ Recovery} = \Sigma \frac{Ci\ Xi}{Cf} \times 100$$

where Ci = concentration of a contaminant in a product stream
Xi = mass fraction of the product stream
Cf = concentration of the contaminant in the feed

Percent recovery was calculated based on the overall THC mass balance as well as the mass balance developed during the SITE sampling. All of the percent recoveries exceed 100 percent, but in general the deviation from 100 is not alarming when one considers the uncertainties in sampling, analyses, and the mass balance estimates. In general, the percent recovery values agree quite well between the overall mass balance approach (THC) and the SITE sampling mass balance.

The data from Table C-7 were used to calculate the percentage of each contaminant by product stream. This information is presented in Table C-8 on the basis of THC overall mass balance estimate and in Table C-9 based on the SITE demonstration mass balance. In each case, the process shows the recovery of a high proportion of the contaminants in the fine slurry with significant reductions in the contaminants in the product gravel and sand. Removal percentages for individual contaminants can be calculated from the number in parentheses in Table C-8 and C-9 by subtracting that number from 100%. Negative numbers result when there is an apparent concentration of the contaminant. In general, the contaminated fine slurry contains about 4 times the concentration of organic constituents as present in the feed soil.

C.4 Bioslurry Reactor Process

The developer had configured the biological treatment system to allow either batch or continuous operation. The developer planned to run batches of slurry to define desired operating and retention times and then to shift to a continuous or at least semi-continuous operation. The sampling plan had been developed for a continuous process so that a steady state or near steady state condition would be available for sampling. In fact, THC had problems with analytical turnaround time and erratic analytical results for oil and grease and benzo(a)pyrene which turned out to be controlling parameters for the process. As a result, THC had not progressed beyond batch operation of the system at the time of the SITE sampling. The procedure in effect was to accumulate a biotreatment batch over a period of several days of 8 hour per day operation of the soil wash plant. Contaminated slurry was pumped periodically from the wash plant and treated with the proprietary oxidant in a flash mix tank. The slurry from a days production was held overnight in a agitated storage tank before being transferred to the bioslurry reactor. In some cases, several days of slurry production were accumulated in the storage tank before transfer to the bioreactor. The bioslurry reactor is aerated to keep the slurry in suspension. Nutrient addition is begun after the entire batch has been transferred to the bioslurry reactor. A batch would consist of 13,000 to 18,500 gallons of slurry. This means that three to five days of operation of the soil wash plant might constitute a batch depending upon the operation time of the soil wash plant, the amount of fines and the concentration of fines in the slurry. Nutrients are added in solution form at a dosing level based on the solids content usually every other day. THC will not provide specific information on the nutrient or oxidant additions for each batch based on a claim that it is proprietary process information.

A sampling team returned on two different dates to sample the discharge of two bioslurry batches. The first batch was identified as batch 2c which was accumulated during the period of March 25 through March 31, 1992 and was initiated on nutrients on April 1, 1992. This batch was discharged by pumping the slurry to the original excavation site on May 11, 1992. This results in a retention from the time of nutrient addition to discharge of 41 days. Seven grab samples were taken over the 100 minutes required for discharge.

The second batch sampled was identified as batch 2a. It was accumulated primarily during the period of SITE sampling of the soil wash process. The actual dates are April 14 through April 21, 1992. Nutrient addition was initiated on April 22, 1992. This batch was discharged to the original excavation site on May 22, 1992. This results in a retention time from first nutrient addition to discharge of 30 days. Seven grab samples were taken over the 120 minutes required for discharge.

The developer determined the retention time required by periodically sampling the batch and comparing the results to the criteria. Erratic analytical results that the developer believes resulted from the high biological content of the samples prevented reliable optimization of the retention times.

C.4.1 Results and Discussion

Characterization data for the contaminated slurry from the attrition soil wash process are applicable to the feed to the bioslurry process. These data are reproduced in Table C-10. Data from the sampling of the discharge of the batch 2c are presented in Table C-11 and similar data for batch 2a are presented in Table C-12.

Both bioslurry batches exceeded the THC Target Criterion for oil and grease which is 1 percent for medium and fine soils. Batch 2c exhibited an oil and grease value of about 5 percent while batch 2a showed an average value of 2.5 percent. The developer believes this is occurring because the oil and grease procedure is extracting biological fats and oils from the biomass present.

Both batches also exceed the THC Target Criterion for benzo(a)pyrene which is 2.4 mg/kg. Batch 2c had an average benzo(a)pyrene level of 3.2 mg/kg and batch 2a had 2.6 mg/kg. The benzo(a)pyrene levels in the discharge were above the detection limit but below the quantitation level for this analysis. This occurred because the samples had a much higher than expected organic content perhaps because of high microbial content. This required the laboratory to extract only 10 percent of one original size

Table C-7. Selected Feed and Product Characteristics of the Attrition Soil Wash Process.

	Feed Soil[1][2]	<1.97 in.; >0.24 in. Clean Gravel[2]	<0.24 in. Coal/Peat Fraction[3]	<0.24 in.; >0.0025 in. Clean Sand[2]	<0.0025 in. Cont. Fines[2]	% Recovery[4]	% Recovery[5]
Percent of Feed Based on Site Demo. Data		11.5	1.6	68.1	18.8		
Percent of Feed Based on THC Overall Analysis	--	10.5	2.5	70.2	16.7		
Oil & Grease mg/kg	8233	3333	38,100	2183	40,000	116	120
TRPH mg/kg	2542	814	11,850	621	14,000	124	131
Copper mg/kg	18.3	6.4	32.9	13.8	83.1	137	144
Lead mg/kg	115	45.3	406	46	522	117	122
Zinc mg/kg	82.5	46	210	34.1	344	111	117
Naphthalene mg/kg	11.15	2.62	64	2.05	51.7	107	112
Benzo(a)pyrene mg/kg	(1.91)[6]	(0.58)	(14.5)	(0.53)	(10.0)	129	133

(1) Feed soil characteristics were calculated from rock and fines analytical data using a weight basis.
(2) Average of six composite samples.
(3) Average of three composite samples.
(4) Percent recovery determined by comparison of the total contaminant accounted for in each product with the feed material based on overall product fraction analysis provided by THC.
(5) Percent recovery determined by comparison of the total contaminant accounted from each product with the feed material based on measurements during the SITE demonstration.
(6) () indicates value reported is below quantitation limit but above detection limit, value should be considered an estimate.

Table C-8. Partition of Selected Parameters in the Product Stream of the Attrition Wash Process (based on THC estimate of overall product yields for this soil).

	<1.97 in; >.24 in Trommel Oversize	<.24 in; Coal/Peat Fraction	<.24 in; >0.0025 in Clean Sand	>0.0025 in Contaminated Fines
Fraction of Feed	.105	.025	.702	.167
Oil & Grease	.037[1] (35)[2]	.100 (400)	.161 (23)	.702 (420)
TRPH	.027 (26)	.094 (376)	.138 (20)	.741 (444)
Copper	.027 (26)	.033 (131)	.387 (55)	.554 (332)
Lead	.035 (34)	.076 (302)	.241 (34)	.647 (388)
Zinc	.055 (52)	.035 (139)	.262 (38)	.628 (334)
Naphthalene	.023 (22)	.134 (536)	.121 (22)	.723 (433)
Benzo(a)pyrene	.025 (24)	.147 (588)	.151 (22)	.677 (405)

(1) Weight fraction of the specific parameter found in the product stream as a fraction of the total weight in all product streams.
(2) Percent of expected value based on feed concentration of respective contaminants and weight fraction of product stream.

Table C-9. Partition of Selected Parameters in the Product Stream of the Attrition Wash Process based on data developed during SITE demonstration.

	<1.97 in; >0.24 in Trommel Oversize	<.24 in Coal/Peat Fraction	<.24 in; >0.0025 in. Clean Sand	>0.0025 in Contaminated Fines
Fraction of Feed	.115	.016	.681	.188
Oil & Grease	.038[1] (33)[2]	.061 (381)	.149 (22)	.752 (400)
TRPH	.028 (24)	.057 (356)	.127 (19)	.788 (419)
Copper	.028 (24)	.020 (125)	.358 (53)	.594 (316)
Lead	.037 (32)	.046 (289)	.223 (33)	.694 (369)
Zinc	.053 (50)	.057 (230)	.262 (38)	.628 (334)
Naphthalene	.024 (21)	.082 (513)	.113 (17)	.781 (415)
Benzo(a)pyrene	.028 (24)	.091 (569)	.142 (21)	.740 (394)

(1) Weight fraction of the specific parameter found in the product stream as a fraction of the total weight in all product streams.
(2) Percent of expected value based on feed concentration of respective contaminants and weight fraction of product stream.

Table C-10. Concentration of Selected Parameters of the Contaminated Slurry Feed to the THC Bioslurry Reactors.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average	Standard Deviation
Oil & Grease mg/kg	40,000	33,300	50,500	54,300	35,300	26,900	40,000	10,500
TRPH mg/kg	12,300	8,500	19,800	18,100	13,600	12,200	14,100	11,417
TOC mg/kg	117,000	102,000	143,000	113,000	130,000	94,700	116,600	17,800
Cu mg/kg	57.4	48.2	76.0		135	99	83.1	34.9
Pb mg/kg	421	334	525		680	651	522	148
Zn mg/kg	219	192	250		593	467	344	177
Naphthalene mg/kg	49.0	52.0	82.0	45.0	65.0	(17.0)*	51.7	21.7
Benzo(a)pyrene mg/kg	(9.0)	<32.0	(9.6)	(11.0)	(12.0)	(8.4)	(10.0)	1.48

*() Indicates value is below quantitation limit for procedure. Value shown is estimated.

Table C-11. THC Bioslurry Process Concentration of Selected Parameters in Discharge Slurry from Bioslurry Reactors - Batch 2c

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Average	Standard Deviation	No
Oil & Grease mg/kg	60,800	47,300	NR	56,600	39,600	40,500	54,1003	49,800	8750	6
TRPH mg/kg	9530	7260.	7400	7620	6870	6800	9270	7820	1120	7
Cu mg/kg	113	99.4	91.5	111	91.6	89.8	111	101	10.4	7
Pb mg/kg	846	718	643	769	652	477	719	689	116	7
Zn mg/kg	469	420	385	464	389	462	504	442	447	7
Naphthalene mg/kg	<16.0	<14.0	<12.0	<16.0	<13.0	<15.0	<16.0	--	--	
Benzo(a)pyrene mg/kg	(2.3)[1]	(4.5)	(2.0)	(5.7)	(2.7)	(2.7)	(2.1)	(3.15)	1.41	7

1 () Indicates value is below quantitation limit for procedure. Value shown is estimated.

Table C-12. THC Bioslurry Process Concentration of Selected Parameters in Discharge Slurry from Bioslurry Reactors - Batch 2a

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Average	Standard Deviation	No
Oil & Grease mg/kg	23,100	39,600	NR	22,000	23,300	21,700	22,2003	25,300	7030	6
TRPH mg/kg	4320	6580	7560	3930	5380	5470	4870	5440	1270	7
Cu mg/kg	898	89.4	108	75.9	69.3	70	82.5	83.6	13.6	7
Pb mg/kg	574	583	713	505	452	474	534	548	87.4	7
Zn mg/kg	370	360	438	316	285	293	340	343	52.7	7
Naphthalene mg/kg	<14.0	<14.0	<16.0	<11.0	<12.0	<11.0	<12.0			
Benzo(a)pyrene mg/kg	(2.4)[1]	(2.3)	(2.8)	(2.9)	(3.4)	(2.6)	(2.6)	(2.6)	0.212	7

1 () Indicates value is below quantitation limit for procedure. Value shown is estimated.

sample and resulted in much higher quantitation levels than were expected. A NBS library search was conducted in an attempt to distinguish the identity of the compounds causing the large background interference in these samples. It is difficult to narrow down the exact nature of the interfering compounds but there appears to be large amounts of unsaturated hydrocarbons and oxygenated hydrocarbons present. This observation fits well with the THC biomass theory.

The THC target criteria for benzo(a)pyrene of 2.4 mg/kg is based on the proposed Province of Ontario target level. Canadian (federal) and European criterion for benzo(a) pyrene is 10 mg/kg.

The same interference had an adverse effect on naphthalene analysis which is a compound that exceeded the THC Target Criterion in the feed soil. Naphthalene was not detected in the discharge from either bioslurry reactor batch but the quantitation limits did not allow a definitive statement. As a partial remedial action, the extracts from one sample of each batch were reanalyzed to establish that storage of the extracts had not had a significant effect on the GC/MS results. The extracts were then spiked with 5 ppm of naphthalene and benzo (a) pyrene and reanalyzed. The analytical variability of the replicates was quite low, and the spike recovery was excellent. The purpose of analyzing these samples was to demonstrate that the instrument detected concentrations below the quantitation limit with a reproducible degree of precision. The net result is that we can conclude that if naphthalene was present at the THC Target Criterion level of 8 ppm, it would have been detected. The reproducibility and excellent spike recovery for the benzo(a)pyrene suggest the levels reported are good estimates.

Another approach to estimating actual naphthalene levels was to examine the minimum estimated values reportable by the method. The rationale being that if naphthalene were present at that level it would have also been estimated. Therefore, the naphthalene level must be below the lowest estimated value. This results in a conclusion that naphthalene concentration is below 1.6 mg/kg.

Table C-13 summarizes the comparison of bioslurry system inlet and outlet for bioslurry batch 2a. The results for bioslurry batch 2c are not directly related to the SITE inlet concentrations but appear to provide similar results.

Table C-13. THC Bioslurry Process Bioslurry Reactor Inlet and Outlet Concentrations for Selected Parameters

	Contaminated Fine Slurry	Bioslurry Batch 2a Discharge	Apparent Removal %
Oil & Grease mg/kg	40,000	25,300	36
TRPH mg/kg	14,000	5,440	61
Cu mg/kg	83.1	83.6	—
Pb mg/kg	522	548	-5
Zn mg/kg	344	343	--
Benzo(a)pyrene mg/kg	(10.0)[1]	(2.6)	74
Naphthalene mg/kg	57.7	<13.0[2]	75
Naphthalene mg/kg	<8.4[3]	84	
Naphthalene mg/kg	<(1.6)	97	

1. () indicates value is below quantitation limit for procedure. Value shown is estimated.
2. Based on average quantitation limit for 7 samples.
3. Based on reanalysis of spike sample to establish if naphthalene was present at this level it would have been detected, therefore true concentration is less.
4. Based on the instrument detection limit of 1/10 the quantitation limit.

C.5 Metals Removal Process

The low level of metals contamination found in Soil B resulted in THC not running this soil through the metals removal process since it was not required to meet the THC Target Criteria. At the time of the SITE sampling the metals removal process was just being restarted after a prolonged shutdown caused by a pump failure and a replacement part availability problem. During the three day SITE sampling event of the soil wash process the metals removal process was operated to empty the two feed tanks which were full of acidified slurry left from the last days of processing Soil A in the wash process. The slurry was produced between March 16, and 18, 1992, and had been acidified and agitated by submerged pumps in the intervening period. Agitation of the feed storage tanks normally is discontinued prior to the transfer of slurry to the tubular reactor where the slurry is contacted with the ion exchange media to allow large soil particles which are carried over from the soil wash process to settle to the tank bottom. The large soil particles can cause problems in the recovery and cleaning of the media before it enters the regenerating tubular reactor. For the demonstration evaluation, slurry to feed the tubular contactor was drawn from the tank about 2 feet from the tank floor. Coarse particles would be removed from the tank bottom only when they interfered with operation or the soil being processed was to be changed. This combination of not being able to sample the actual feed soil and some unknown separation by sedimentation in the tank led to the development of a sample plan in the field that involved sampling only the influent and effluent slurries for the tubular contactors. No inferences can be made concerning the THC Target Criteria. The evaluation was limited to determining the removal levels achievable with the tubular ion exchange media contactor.

Composite samples of the influent and effluent were accumulated by taking hourly grabs over a four hour period. During the first sampling day, two composites (#1, #2) were accumulated. During the second day of sampling, the first four hour composite (#3) was accumulated as planned. During the accumulation of the second composite (#4), the contents of the first tank were exhausted. The feed was initiated from the second tank. Composite #4 which was the second composite of the second sampling day was terminated after 2 hours and a new composite sample (#5) for the new feed tank was initiated. After accumulating 2 hourly grabs, the operator noticed that the media was being fouled with oil and the run was terminated. The reactor and media required extensive cleanup and, as a result, operations were not resumed during the SITE sampling time frame. The cause of the oil contamination was later identified as the contents of the second feed tank. THC had processed the fines generated by the soil wash process while processing roughly 830 tons of this soil without encountering this problem. A good explanation has not emerged but a definite process limitation has been identified. Plans to confirm operating flow rates on the third day of sampling were precluded by the process shutdown. The developer reports that slurry feed rate was normally 8 gallons per minute with a 24 percent solids level. This results in the actual processing of about 0.55 tons per hour of dry solids.

The composite samples were analyzed for total metals. The slurries proved amenable to extractions as a liquid. Table C-14 presents the analytical results for the composite samples. The inlet metals concentrations are very consistent including composite sample #5 which was obtained during operation from the second feed tank. Outlet metals values exhibit greater variation from composite sample to composite sample. Table C-14 also presents percentage removal information by metal based on comparison of the composite average inlet and outlet concentrations. The values obtained are in the range of expected results based on THC experience.

C.6 Emissions Sampling

The ventilation system for the bioslurry process was sampled for gaseous emissions in an effort to establish the types of emission control which might be required. Minor amounts of volatile organics were detected. Analysis of SVOC's was handicapped by the poor detection limits as a result of high concentrations of non-target hydrocarbons which were tentatively characterized between diesel distillates and Stoddard solvent (C_9 to C_{16} parafines). Total gaseous non-methane organic compounds were detected at levels which indicate 220 pounds per day of emissions from the overall bioslurry system. It is reasonable to expect this emissions rate would be highly variable depending upon the specifics characteristics of the soil being processed as well as operating rates. The significance of this result is that air stripping in the bioslurry reactors is responsible for removing at least part of the hydrocarbons present. Adequate emissions control will be essential in application of this technology. The THC facility has in place a biological filter system and carbon adsorption beds for emissions control. These treatments were intentionally over designed to meet regulatory concerns. No effort was made to assess the effectiveness of the control measure. Stack testing by the developer indicates hydrocarbon emissions are below detection.

Table C-14. Metals Removal Process - Inlet and Outlet to Tubular Reactor Data for Selected Metals.

	Total Metal (mg/L)							
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average	Standard Deviation	% Removal
INLET METALS								
Copper	49.2	50.2	50.0	53.2	52.2	51.0	1.53	
Lead 100	97.8	94.2	98.4	112.0	100.5	6.8		
Nickel 11.2	12.7	10.7	11.7	12.0	11.7	.8		
Zinc 284	270	264	273	294	277	12		
OUTLET METALS								
Copper	1.6	3.0	(.9)*	1.76	1.7	1.8	.8	96
Lead 22.0	41.6	28.6	13.5	39.3	29.0	11.8	71	
Nickel 4.7	7.3	(1.2)*	(.9)*	2.6	3.3	2.7	77	
Zinc 55.4	103	110	53	183	100.9	52.9	64	

* ( ) Indicates value is below quantitation limit for procedure. Value shown is estimated.

Appendix D-1

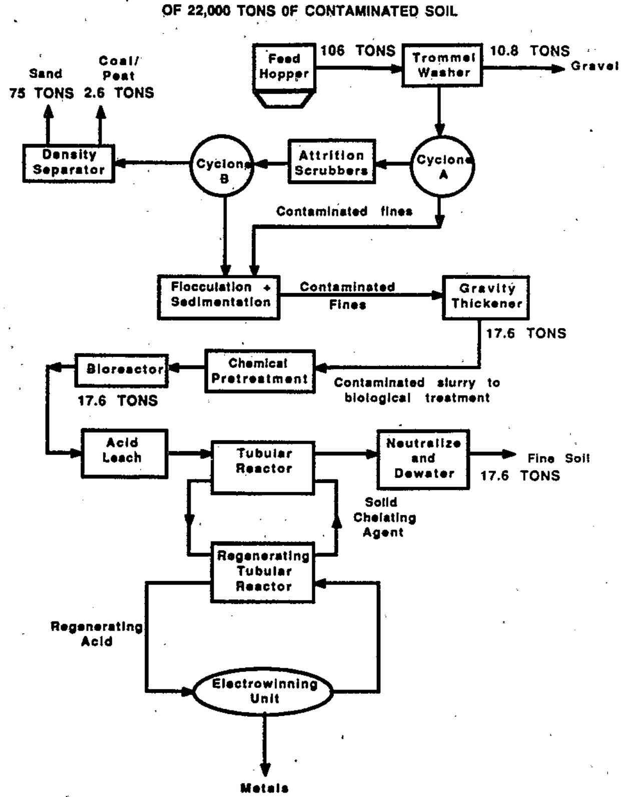
Cost Analysis for Treatment of 22,000 Tons of Contaminated Soil Using the THC Treatment Plant

D.1 Introduction

The volume of soil that may require treatment at the Port Industrial District has been estimated at 2,200,000 tons. For purposes of this analysis we have constructed a hypothetical case in which 22,000 tons of soil on a dry basis with a fines content of 16.5 percent which requires treatment for heavy metals and organic contaminants will be processed in the existing THC Treatment Plant.

Figure D-1 presents a process flow diagram with average daily flows indicated for this hypothetical case.

FIGURE D-1
DAILY MASS FLOWS FOR HYPOTHETICAL CASE TREATMENT OF 22,000 TONS OF CONTAMINATED SOIL



This economic analysis is based on assumptions and costs provided by THC or its contractors. This estimate is based on an analysis of costs incurred during the 9 months of plant operation experience accumulated in 1992. THC provided a cost analysis based on an assumption of 33 percent fines in the soil. This represents a worst case scenario for costs. Several other cases have been examined in order to highlight the importance of the amount of fines in the overall costs for the treatment train. The THC analysis was provided in Canadian dollars. It has been converted to U.S. currency by using an exchange rate of $0.80 U.S. to $1.00 Canadian. Comments on the cost analysis and discussion of cost elements in general represent the author's engineering judgement. An effort has been made to present the cost analysis in a manner that will allow the reader to vary the basis to fit a particular situation or to evaluate the sensitivity of cost to a particular assumption.

Cost figures provided here are based on analysis of the actual operation of the actual plant and actual personnel. The analysis involved identifying achievable long term production levels and utilizing actual cost experience to project costs when production is the primary goal of the operation. The costs presented include a profit for the developers. This "profit" is recovered in the equipment cost as well as a loading on labor. The exact nature of the "profit" has not been disclosed.

Utilization Rates and Maintenance Schedules - The processing of 22,000 tons of soil would require about 208 days of operation. In order to account for scheduled maintenance and unscheduled shutdowns due to equipment problems, a 10 percent factor has been assumed. This results in 229 day operation being required and an effective operating rate of 96 tons/day of feed soil. Costs for labor and equipment were increased to reflect this allowance. Consumables, utilities, and analytical costs were not factored since these elements are not consumed during downtime periods.

Financial Assumptions - For the purposes of this analysis, capital equipment costs are separated for the complete process units. Capital equipment costs were amortized over a 10 year period with no salvage value taken at the end of the period. Interest rates, time-value of money were included by the developer. The effective rate used by the developer, based on an analysis of the data provided is 20%. The reader is cautioned that interest rates in Canada are considerably higher than in U.S. at this time, however it is clear that a return on capital is also included here.

D.2 Basis for Economic Analysis

In order to compare the cost effectiveness of technologies in the SITE program, EPA breaks down costs into 12 categories shown in Table D-1 using the assumptions already discussed. The assumptions used for each cost factor are described in more detail below.

D.2.1 Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner). These costs may include actual permit costs, system health/safety monitoring and analytical protocols. Permitting and regulatory costs can vary greatly because they are very site- and waste-specific. No permitting costs are included in this analysis; however, depending on the treatment site, this may be a significant factor since permitting can be expensive and a time-consuming activity. THC has obtained the permits required for its facility however, they are based upon the facility being completely removed after the evaluation.

D.2.2 Site Preparation Costs

The amount of preliminary preparation will depend on the site and is assumed to be performed by the responsible party (or site owner). Site preparation responsibilities

Table D-1. Treatment Cost Summary for a Hypothetical Remediation of 22,000 tons of Soil with 16.5 Percent Fines and Both Organic and Inorganic Contaminants.

Cost Component	Soil Wash	%	Biological Treatment	%	Metals Removal	%	Total	%
1. Site Preparation Costs	N/A		N/A		N/A		N/A	
2. Permitting & Regulatory Costs	N/A		N/A		N/A		N/A	
3. Equipment Costs	$317,300	20	$71,100	15	$246,900	22	$635.300	20
4. Startup	N/A		N/A		N/A		N/A	
5. Labor	$872,300	55	$259,800	54	$656,900	57	$1,789,000	56
6. Consumables & Supplies								
Chemicals	$66,800	4	$26,800	6	$100,000	9	$193,600	6
Maintenance Supplies	$53,400	3	$13,800	3	$43,400	4	$110,600	3
7. Utilities								
Electric	$233,200	15	$83,400	17	$66,800	6	$383,400	12
8. Effluent Treatment & Disposal	N/A		N/A		N/A		N/A	
9. Residuals/Waste Shipping, Handling & Transport Cost	N/A		N/A		N/A		N/A	
10. Analytical Costs	$53,200	3	$26,800	6	$26,800	2	$106,800	3
11. Facility Modification, Repair & Replace	N/A		N/A		N/A		N/A	
12. Demobilization Cost	0		0		0		0	
Total	$1,596,200	100%	$481,700	100%	$1,140,800	100%	$3,218,700	100%
Cost/Ton	$72.55		$21.90		$51.85		$146.30	

include site design and layout, surveys and site logistics, legal searches, access rights and roads, and preparations for support facilities, decontamination facilities, utility connections, and auxiliary buildings. These preparation activities have been undertaken by THC at this location. A specific provision has therefore not been included in the cost analysis.

D.2.3 Equipment Costs

Capital equipment costs are broken down into the three technologies demonstrated under the SITE program, i.e., Attrition Soil Washer, Biological Treatment Process, and a Metals Removal Process. The equipment was acquired in 1991 and the capital installed costs for each technology has been provided by THC in Canadian dollars. This estimate includes the allocation of the primary plant air handling system costs equally among the three processes.

D.2.3.1 Attrition Soil Washer

The unit utilized during the THC demonstration is the same unit which is used in this hypothetical case. It utilizes a system of trailer transportable modular units which are assembled at the site into an integrated unit. It is designed to provide flexibility so that it can be used with a variety of feed soils. The unit was supplied as a package by a supplier who designed the unit based on experience with similar units in Europe. The unit employs mineral processing equipment from North America, if available. THC leased the unit with the operators for this demonstration. The cost analysis is based on the purchase of an equivalent unit with operation by THC. The capital cost for the installed unit, including a carbon adsorption unit for air emissions is reported to be $1,200,000 U.S. The cost recovery for the 22,000 ton case would be $317,300, which includes the amortized cost of equipment plus rental equipment and building charges.

D.2.3.2 Biological Treatment Process

The biological treatment system has a reported installed cost of $240,000 U.S. The equipment cost for our case of $71,100 U.S. includes the cost of rental equipment and a building charge.

D.2.3.3 Metals-Removal Process

This unit is also a trailer transportable modular design. The unit incorporated by THC is the first unit of this size manufactured anywhere. The equipment is of a unique design which allows the contacting of metals-rich high solids content slurry with solid chelating agent beads without plugging or fouling and restricting the flow through the media. The installed cost of the unit, including an acid gas scrubber for air emissions, is reported to be $800,000 U.S. This results in a equipment cost for this case of $246,900 U.S., which includes the amortized cost of equipment plus rental equipment and building charges.

D.2.4 Start-up

The facility being utilized in the hypothetical case is the one currently located at the THC facility. Start-up with a new soil is very rapid with adjustments to accommodate the soil tending to evolve during early operation. Starting costs have not been broken out by THC and have not been included here.

If the plant is relocated to a new site, the following considerations should be made. In general, the transportation cost for the process units will be a function of how far the units must be moved to the new site. Assembly is a labor intensive operation consisting of unloading modules from truck and trailers used for transportation, as well as the actual assembly. A crane will be required for these operations. A two week time frame for set-up which would involve operators familiar with the assembly of the plant would be required as a minimum.

The cost of health and safety training and monitoring have not been included in this analysis. Depending upon the specific contaminants present in the soil to be treated, these costs would be significant. As a minimum, any local manpower utilized will require OSHA 40 hour hazardous waste training if a superfund site is involved or hazardous materials are to be processed.

D.2.5 Labor

THC has provided labor cost data in Canadian dollars by process and staffing levels but has not provided specific cost per hour for the various labor classifications. Additional labor included an allocation of materials handling labor and a maintenance (parts and labor) element. One-half of the maintenance cost has been allocated to labor and the other half to maintenance parts and consumables. The labor dollars reported include labor rate and fringe benefits and an allocation of technical management, site supervisor, a QC person, and a clerk. Included in overhead are elements such as potable water, telephones, office trailer rentals, site security and snow removal. The cost data provided by THC were based on operations with a feed soil fine concentration of 33.30

percent. This example is based on a 16.67 percent fines soil, such as encountered during the SITE demonstration. The costs presented are based on operating the wash plant for two shifts. THC labor cost elements were doubled for the wash plant. The cost data provided by THC results in a fully loaded average of $42 per hour for the 17.5 people normally included.

Estimate labor cost for the hypothetical case are:

Soil Wash	$872,300
Biological Treatment	$259,800
Metals Removal	$656,900

D.2.6 Consumables and Supplies

The three processes each consume chemicals utilized in the respective treatments. THC has not disclosed the identity of specific chemicals being utilized so the cost information is aggregated by process. The cost information provided by THC aggregated maintenance, labor, and parts and materials in one cost element. This element has split one-half to maintenance materials and the other half as labor. Safety equipment and supplies were included in the site overhead which was allocated to labor. A discussion of the chemicals utilized and maintenance materials by process follows.

D.2.6.1 Attrition Soil Wash

Chemicals utilized are flocculents consumed in thickening the contaminated slurry. Total cost of chemicals of $66,800 was calculated for this process in this hypothetical case.

The maintenance supplies would include fuel for equipment, lubricants, and parts such as bearing and seal materials as well as parts for the conveyor system which feeds the trommel washer. The wash plant is a damp, harsh environment with a considerable number of high speed pumps and washer cells. In addition, vibratory equipment is utilized. Maintenance expense for this hypothetical case was estimated as $53,400.

D.2.6.2 Biological Treatment Process

The biological treatment system consumes the inorganic oxidant, phosphoric acid solution and urea solution in processing the slurry. Chemicals costs for the hypothetical case are estimated to total $26,800.

Maintenance parts and supplies would include lubricants for the primary compressor, spare parts for the compressor and the transfer pumps utilized. These costs were estimated at $13,800.

D.2.6.3 Metals Removal Process

The cost of the solid chelating agent beads is included in the capital cost and thus amortized over a 10 year period. This assumes little attrition or chemical degradation of the media will occur. It is too early to judge the wisdom of this assumption since a considerable period of operation will be required to establish useful life information for the media. This process utilizes a mineral acid to dissolve heavy metals prior to its removal by the chelating agent. A second acid is utilized to regenerate the solid chelating agent. The slurry is neutralized using a caustic solution prior to being pumped to the biological treatment system or returned to the excavation site. The total cost for process chemicals for the hypothetical case is estimated at $100,000.

Maintenance materials for this process can be expected to primarily center on the pumps used to transfer the acidified slurry through the process. This is a very harsh application and parts availability did cause delays during the overall THC demonstration. The estimated maintenance supply cost for the hypothetical case is $43,400.

D.2.7 Utilities

The THC demonstration plant was designed utilizing electrical energy for all requirements. This approach was adopted since permits were required for any fossil fueled boilers or process equipment. The attrition soil wash process requires water at a temperature of at least 55°F (13°C). This facility utilized an electric powered steam boiler to generate steam for heating the soil wash plant water recycle stream. Operations of the facility through the first half of 1992 suggest that this boiler consumes more electrical energy than the rest of the facility combined. THC took this into consideration and than allocated the remaining electrical energy cost to the respective processes based on installed horsepower and operating times. Common support, primarily the air handling system, was allocated equally among the three processes. Bioslurry process costs are primarily for the compressor to provide process air. The cost of electrical energy at the site is $0.104 U.S. per KWH. The resulting electrical cost allocations for our hypothetical case are:

Attrition Soil Wash	$233,200
Biological Process	$83,400
Metals Removal Process	$68,800

Process water was obtained from the collection of precipitation runoff supplemented as required by pumping water directly from Lake Ontario. No specific cost for water was included.

D.2.8 Effluent Treatment & Disposal

The process, even with effective dewatering in place, can be expected to use some water since a considerable amount of water leaves the process with the products. In the case of the demonstration, the contaminants present did not partition to the aqueous phase. During the nine month THC demonstration water from excess precipitation was discharged to the local POTW. The sedimentation available in the basin system was sufficient to meet TSS and oil and grease discharge criteria. No significant cost factor was involved.

Air emission controls for the overall system include a multichamber biological filter system followed by a carbon adsorption bed polishing step. THC has developed data which suggest this system results in emissions without detectable hydrocarbons. In addition, the carbon appeared new. Additional operating experience will be required to establish the frequency at which the biological media (peat) and the carbon must be replaced and disposed of. No attempt was made to estimate these costs.

The overall process generates two solid waste streams that will require use or disposal approaches. The first stream is the coal/peat material removed in the soil washer density separator. This material is primarily <.24 inch coal and fragments of wood and roots which are in various stages of decay. Depending on the contaminants present, this material could be used as a fuel in an industrial boiler. If hazardous contaminants are present, it may require disposal, most likely by incineration. The stream accounted for 2-3 percent of the feed soils examined by THC. This waste was not disposed of during the THC demonstration but could result in considerable cost if incineration were required. For example, in this hypothetical case this waste would amount to 550 ton. If incineration could be assumed to cost $1000/ton the cost incurred would be $550,000 and would represent a significant cost factor.

In a full scale facility it may be desirable, depending on the characteristics of the soil, to remove the coal and wood debris that reports to the coarse gravel product (1.97 inch >.24 inch). This could be achieved with a vibratory density separator similar to that employed on the clean fine sand. This would generate an additional waste stream which would require a use or disposal.

The metals removed by the electrowinning in the metals removal process generally represent a small fraction of the feed soil on a weight basis. The developer believes that the metals values may be recoverable. In any event the heavy metals removed are highly concentrated so that the volume of hazardous material is greatly reduced. No estimate of cost associated with utilizing or disposing of this waste has been developed.

D.2.9 Residuals/Waste Shipping, Handling and Transport Costs

Waste disposal costs including storage, transportation and treatment costs would be the obligation of the responsible party. Because of the nature of the soils treated at the THC demonstration, residuals requiring special handling were not generated.

In cases where hazardous contaminants are present, residual or solid wastes would consist of contaminated health and safety gear, used filters, personal protective clothing, activated carbon, etc. Landfilling or incineration would be the anticipated disposal method for these types of materials. In cases where such materials will require disposal the costs may be significant and should be included.

D.2.10 Analytical Costs

Analytical costs have been estimated for the treatment train based on a weekly provision for process assessment and quality control. The budgets provided for this hypothetical case are:

Attrition Soil Wash	$53,200
Biological Process	$26,800
Metal Removal	$26,800

If hazardous components are present in the feed soil, sampling of the products prior to their return to a site would be required by the appropriate regulatory agency. The cost for the testing will require assessment based on the specific contaminants and the requirements of the regulatory agency.

D.2.11 Demobilization Costs

Some of these costs would be site-specific. See Section D 2.4 on start-up for an understanding of what may be involved. No demobilization costs have been included in this analysis.

D.3 Results

Table D-1 shows a total cleanup cost for the hypothetical treatment of 22,000 tons of contaminated soil in the existing THC Treatment Plant of $3,218,000. The costs are also itemized by cost category and treatment process. The soil wash process accounts for about 50 percent of the total cost while the metals removal process accounts for about 35 percent of total cost and the biological treatment accounts for the remaining 15 percent. The soil wash process will process the entire 22,000 tons of feed while the other processes are required to treat only the contaminated fines, which for this analysis amounted to approximately 3650 tons. When considering the overall treatment train, the largest cost components are labor (56%), equipment costs (20%), and electrical energy (12%), consumables (10%) and analytical cost (3%) account for the remaining costs.

Based on this hypothetical case of 22,000 tons dry basis of contaminated soil treated, the total estimated unit cost is $147/ton; the breakdown of costs by technology is shown below.

	Unit Cost $/ton
Attrition Soil Washer	73
Biological Treatment Process	22
Metals Removal Process	52
Total	$147

This cost estimate is based on a fines content of 16.5 percent. The estimated cost per ton is quite sensitive to the percent of fines present. This occurs because the metals removal and or biological treatment capacity can limit the utilization of the wash plant if this treatment is operated at .73 ton per hour throughput. There is no magic in that throughput rate since the throughput required to meet a specific required metal removal or biological treatment may vary. The .73 ton throughput rate is simply a good operating assumption. Tables D-2, D-3 and D-4 illustrate the effect of different fines concentration on cost if the metals removal and biological system are limited to .73 ton/hr throughput. The case illustrated in Table D-2 is for a soil fine concentration of 33 percent which THC provided as the base case. In general, this is considered the upper limit of fines content applicability for the overall treatment strategy. This case would utilize the wash process only about 40 hours per week. Table D-3 and D-4 illustrate the cases in which the soil wash plant could be operated 80 hours per week and 120 hours per week respectively as a result of the respective fine contents.

These cost estimates are summarized below.

	Cost $/ton of feed soil		
	33% Fines	16.5% Fines	11% Fines
Attrition Soil Process	80	67	63
Biological Treatment	43	21	14
Metal Removal Process	96	48	32
Total	219	136	109

These cost estimates do not have any allowance for operating downtime other than that already built into the THC analysis.

Cost of the metals removal process and biological treatment system are expressed on a per unit of throughput basis. Table D-5 is based on a 0.73 ton dry basis per hour throughput. Viewed on this basis the estimated costs are as follows:

	Unit Cost $/ton actually processed
Attrition Wash Plant	287
Biological Treatment Process	128

The reader is cautioned that the costs accounted for in this analysis do not include some site specific elements which could significantly effect final costs. In addition capital and operating cost for an appropriate dewatering process must also be included. If incineration of the coal/peat waste is required, the cost would be a significant factor. THC has assumed an operating throughput rate for the metals removal process somewhat higher than those observed during the demonstration. The relatively long process times used for the bioslurry reactor process during the demonstration if required would result in the cost estimate for the biological process being low. If retentions of 30 to 40 days are required, the biological process cost could increase by a factor of 3 to 4. Careful treatability studies to establish technical suitability and to refine the cost estimates will be necessary.

Table D-2. Cost Per Ton of Feed Soil Based on 53 Tons Per Day of Feed and 33 Percent Fines in the THC Treatment Train

	Attrition Soil Wash Process	Biological Treatment Process	Metals Removal Process	Total
Labor				
Manpower	$28.36	$17.14	$47.14	$92.64
Maintenance	4.84	2.49	7.86	15.19
Materials Handling	5.19	3.03	3.03	11.25
Purchased Material & Services				
Analytical Charges	2.41	2.41	2.41	7.23
Chemicals	3.03	1.51	9.07	13.61
Energy				
Electrical	10.58	7.57	6.64	24.19
Equipment & Building				
Equipment	21.81	4.36	14.53	40.70
Rental Equipment	2.27	2.27	3.78	8.30
Building	1.81	1.81	1.81	5.43
Total	$80.30	$42.54	$95.67	$218.56

Table D-3. Cost Per Ton of Feed Soil Based on 106 Tons Per Day of Feed Soil and 16.5 Percent Fines in the THC Treatment Train.

	Attrition Soil Wash Process	Biological Treatment Process	Metals Removal Process	Total
Labor				
Manpower	$28.36	$8.57	$23.57	$60.50
Maintenance	4.84	1.24	3.44	10.02
Materials Handling	5.19	1.52	1.52	8.23
Purchased Material & Services				
Analytical Charges	2.41	1.22	1.22	4.85
Chemicals	3.03	1.22	4.54	8.74
Energy				
Electrical	10.58	3.78	3.03	17.39
Equipment & Building				
Equipment	10.90	1.10	7.29	19.28
Rental Equipment	1.14	1.14	1.90	4.18
Building	.91	.91	.91	2.73
Total	$67.36	$20.70	$47.91	$135.97

Table D-4. Cost Per Ton of Feed Soil Based on 159 Tons Per Day of Feed Soil and 11 Percent Fines in the THC Treatment Train.

	Attrition Soil Wash Process	Biological Treatment Process	Metals Removal Process	Total
Labor				
Manpower	$28.36	$5.72	$15.71	$49.79
Maintenance	4.84	.83	2.62	8.29
Materials Handling	5.19	1.01	1.01	7.21
Purchased Material & Services				
Analytical Charges	2.41	.81	.81	4.03
Chemicals	3.03	.50	3.03	6.56
Energy				
Electrical	10.58	2.52	2.01	15.11
Equipment & Building				
Equipment	7.28	1.45	4.84	13.57
Rental Equipment	.75	.75	1.26	2.76
Building	.60	.60	.60	1.80
Total	$63.04	$14.19	$31.89	$109.12

Table D-5. Cost Per Ton of Soil Actually Processed Based on Through-put Rate of .73 Ton/Hr and Continuous Operation.

	Biological Treatment Process ($/Ton)	Metals Removal Process ($/Ton)
Labor		
Manpower	$51.40	$141.40
Maintenance	7.44	23.59
Materials Handling	9.07	9.07
Purchased Material & Services		
Analytical Charges	7.26	7.26
Chemicals	4.54	27.22
Energy		
Electrical	82.68	18.14
Equipment & Building		
Equipment	13.08	43.62
Rental Equipment	6.80	11.34
Building	5.44	5.44
Total	$127.71	$287.08

Case Study D-2

Attrition Soil Wash Process Results for Soil B

THC's contractors excavated and processed 1040 tons of a soil designated Soil B from a former refinery site located in the PID. The soil was processed in the attrition soil wash plant during the period including March 19, 1992 to May 14, 1992.

Xenon Environmental Laboratories, Inc. was retained to sample the process feed and product streams on four days during the course of the run. The sampling dates were at least one week apart. Samples were accumulated by compositing hourly grab samples over an eight hour period.

Table D-2-1 presents the average results for the four sample events for selected parameters. The partitioning of some key contaminants in the product streams based on this data is illustrated in Figure D-2-1.

FIGURE D-2-1
PARTITION OF FEED SOIL TO PRODUCT STREAMS IN ATTRITION WASH PROCESS., SOIL B, OVERALL THC PROJECT

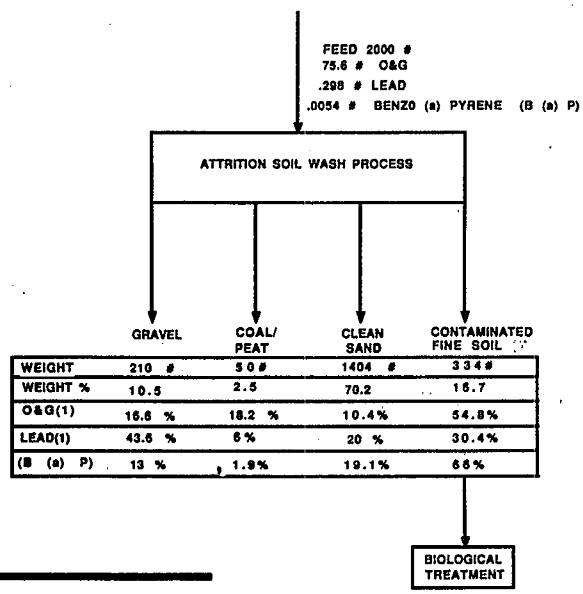


Table D-2-1. Selected Feed and Product Stream Parameters for Attrition Soil Wash Process, Soil B, THC Soil Recycle Treatment Plant.

	Feed Soil	Gravel	Coal/Peat	Clean Sand	Contaminated Fines
Percent of Feed to Trommel Washer		10.5	2.5	70.2	16.7
O&G, %	3.78	5.9	27.3	0.56	5.59
Copper, mg/kg	16.6	42	46.4	11.1	16
Lead mg/kg	149	845	487	58	370
Zinc, mg/kg	53.1	277	140	33	213
Napthalene mg/kg	17.1	40.7	156	3.3	54.2
Phenanthrene, mg/kg	14.8	25.5	160	3.0	56.8
Pyrene, mg/kg	10.3	16.5	109	1.9	36
Benzo(a)pyrene, mg/kg	2.7	3.1	19.1	0.69	10.1

Case Study D-3

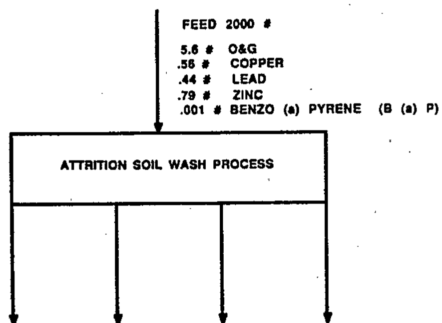
Attrition Soil Wash Process Results for Soil A

THC's contractor processed 820 tons of a soil designated Soil A from a former auto/metal salvage site located in the PID. The soil was processed in the attrition soil wash plant during the period including February 11, 1992 to March 18, 1992. This soil contained wire and roots from vegetation which caused problems when this fibrous material blinded screens or caused flow restrictions in process piping.

Xenon Environmental Laboratories, Inc. was retained to sample the process feed and product streams on four days during the course of the run. The sampling dates were at least one week apart. Samples were accumulated by compositing hourly grab samples over an eight hour period.

Table D-3-1 presents the average results for the four sample events for selected parameters. The partitioning of some key contaminants in the product streams based on this data is illustrated in Figure D-3-1.

FIGURE D-3-1
PARTITION OF FEED AND PRODUCT STREAMS IN ATTRITION WASH PROCESS. SOIL A, OVERALL THC PROJECT



	GRAVEL	COAL/ PEAT	CLEAN SAND	CONTAMINATED FINE SOIL
WEIGHT	280 #	30 #	1326 #	364 #
% OF FEED	14	1.5	66.3	18.2
O&G	19.9 %(1)	5.2 %	18.1 %	56.8 %
COPPER	20.4 %	8.4%	29.7 %	41.5 %
LEAD	14.7 %	2.5%	36.6 %	46.2 %
ZINC	22.9 %	2.1 %	32.3 %	42.7 %
(B (a) P)	2.1 %	18.5 %	9.8 %	69.6 %

(1) PERCENTAGE OF CONTAMINANT BASED ON TOTAL CONTAMINANT IN PRODUCT STREAMS

Table D-3-1. Selected Feed and Product Stream Parameters for the Attrition Soil Wash Process, Soil A, THC Soil Recycle Treatment Plant

	Feed Soil	Gravel	Coal/Peat	Clean Sand	Contaminated Fines
Percent of Feed to Trommel Washer		14	1.5	66.3	18.2
O&G, %	0.28	0.68	1.65	0.15	1.49
Copper, mg/kg	282	331	1268	102	518
Lead mg/kg	219	315	499	166	763
Zinc, mg/kg	394	1057	917	314	1515
Phenanthrene mg/kg	0.92	ND	28.8	0.34	5.9
Pyrene, mg/kg	0.76	ND	18.3	0.22	8.6
Benzo(a)pyrene, mg/kg	0.51	0.20	16.8	0.20	5.2

Case Study D-4

Bioslurry Reactor Process Results at the THC Soil Recycle Treatment Plant for Soil B

An assessment of the bioslurry reactor process for the treatment of contaminated fines produced by the attrition soil wash process and the high pressure wash process for Soil B from a refinery site located in the PID was conducted during the THC Soil Recycle project. The evaluation consisted of the treatment of a series of soil batches.

D.4.1 Oil and Grease

Considerable effort was devoted to the development of analytical procedures to allow reporting of total oil and grease as well as the separate mineral (oil) and animal (grease) components of this parameter. In general, the attainment of total oil and grease at the 1.0 percent target level was not achievable. At least a part of the problem is associated with relatively high levels of animal grease resulting from extraction of the biomass in the treated soil.

Table D-4-1 presents oil and grease (O&G) and component data for the processing of a batch of Soil B from the high pressure soil wash process evaluation.

The initial levels of oil and grease were high, but these levels were brought down steadily as a result of biodegradation, with residual mineral O&G levels (further corrected for the presence of polar compounds) below the 5000 mg/kg THC criteria for mineral O&G attained. This was achieved after 50 days of biodegradation, a lengthy time for treatment. On the other hand, it is the limit of contamination which would be treatable in mesophilic bioreactors such as the ones operated here. Faster treatment could be obtained with thermophilic bioreactors, but it would involve heating to startup the high-temperature biodegradation.

D.4.2 PAH Compounds

The analysis of PAH compounds also required the development of sampling and analytical procedures that will allow the reliable determination of PAH concentration levels in the slurry from the bioslurry reactors. The development of these procedures is an ongoing program.

Results of the PAH treatment of several batches of Soil B contaminated fines generated by the attrition soil wash process are presented in Table D-4-2. Similar data for contaminated fines generated using the high pressure wash process are presented in Table D-4-3.

The biodegradation of benzo(a)pyrene (BAP) to the 2.4 mg/kg level has shown to be an obstacle in the THC refinery soils. Although the percentage of reduction of BAP is significant (above 60%), the criteria level of 2.4 mg/kg has only been achieved for Batch #4, for fines from the attrition soil wash process.

Table D-4-1. Oil and Grease Results for the Biological Treatment of Contaminated Fines from the High Pressure Wash Process

	Average 6 Samples	4278-1196 TK-101	4278-1303 TK-101	4278-1451 TK-101	4278-1497 TK-101	4278-1504 TK-101
Date	4-Aug.	8-Aug.	20-Aug.	2-Sep.	9-Sep.	23-Sep.
Days of Biodeg.	0	4	16	29	36	50
Component	Stand. Method mg/kg	Stand. Method mg/kg	Stand. Method mg/kg	Stand. Method mg/kg	Stand. Method mg/kg	Stand. Method mg/kg
Oil (Mineral)	52167	35000	30000	16000	11000	4500
Oil (Mineral - Methanol)	42500	29000	30000	16000	6000	3700
Grease (Animal)	52500*	140000	23000	22000	9000	8500
Total Oil & Grease (Freon)	105167	170000	54000	38000	20000	13000

* Note: Samples had undergone some anaerobic biodegradation during shipping, explaining the initial high animal O&G counts

Table D-4-2. Comparative Data for Specific PAHs for the Processing of Soil B Contaminated Fines from the Attrition Soil Wash Process

	4278-0581 Fines	4278-0649 R2B	4278-0769 R2C	4278-1038 R2B
	Before tmt	Batch #1	Batch #2	Batch #4
# days biodegradation	0	30	37	34
Component	mg/kg	mg/kg	mg/kg	mg/kg
Phenanthrene	32	5.9	3.9	3.4
Benzo(a)anthracene	19	4.9	1.1	0.55
Chrysene	26	8.6	1.0	0.83
Benzo(b)fluoranthene	15	9.4	2.3	0.96
Benzo(k)fluoranthene	1.2	2.7	ND	ND
Benzo(a)pyrene	16	10	3.9	1.2
Dibenzo(a,h)anthracene	ND	2.0	ND	ND

Table D-4-3. Comparative Data for Specific PAHs for the Processing of Contaminated Fines for the High Pressure Wash Process

	4278 1182 Before tmt	4278-1042 R3	4278-1497 TK-101
# days biodegradation	0	27	30
Component	mg/kg	mg/kg	mg/kg
Phenanthrene	72	44	3.5
Benzo(a)anthracene	13	8.5	1.6
Chrysene	22	16	2.3
Benzo(b)fluoranthene	9.1	6.8	3.1
Benzo(k)fluoranthene	2.3	1.5	0.74
Benzo(a)pyrene	12	6.3	5.7
Dibenzo(a,h)anthracene	ND	1.6	1.3

Case Study D-5

Metals Removal Process Evaluation for Soil A

THC's contractors excavated about 820 tons of soil from a site within the PID which had been utilized as an automobile and metal salvage yard. This soil was designated as Soil A. The soil was processed in the attrition soil washer incorporated in the THC Soil Recycle Project. The contaminated fines produced by the soil wash processes were processed in the metals removal process prior to treatment in the bioslurry reactor process.

Table D-5-1 presents feed concentrations and treated fines concentrations for two 24-hour processing periods for Soil A contaminated fines prepared with the attrition soil wash process. Percent removals calculated from the feed properties are also presented in Table D-5-1.

Table D-5.1 Metals Removal Process Results Soil A Feed for Attrition Soil Wash Process

	Run #1(1) 2/20/92			Run#2(1) 2/21/92		
Metals	Feed Total Metals	Product Total Metals	%(2) Removal	Feed Total Metals	Product Total Metals	%(2) Removal
Cu mg/kg	568	120	79	1223	169	86
Ni mg/kg	298	46	84	469	84	82
Pb mg/kg	800	150	81	1687	211	87
Zn mg/kg	1601	300	81	3072	211	93

1 Each run represented a 24-hour operating period composite sample

2 Percent removal for specific metal removal = $1.0 - \frac{\text{product concentration}}{\text{feed concentration}} \times 100$

☆U.S. GOVERNMENT PRINTING OFFICE: 1993- 753-008